U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN NO. 144.

A. C. TRUE, Director.

IRRIGATION IN NORTHERN ITALY.

Part I.

BY

ELWOOD MEAD,
Chief of Irrigation Investigations.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1904.

OFFICE OF EXPERIMENT STATIONS.

A. C. True, Ph. D., *Director.*
E. W. Allen, Ph. D., *Assistant Director.*

IRRIGATION INVESTIGATIONS.

Elwood Mead, *Chief.*
R. P. Teele, *Editorial Assistant.*
C. E. Tait, *Assistant, in Charge of Central District.*
Samuel Fortier, *Irrigation Engineer, in Charge of Pacific District.*
C. G. Elliott, *Engineer, in Charge of Drainage Investigations.*

LIST OF PUBLICATIONS OF THE OFFICE OF EXPERIMENT STATIONS OI IRRIGATION AND DRAINAGE.

Note.—For those publications to which a price is affixed application should b made to the Superintendent of Documents, Government Printing Office, Washing ton, D. C., the officer designated by law to sell Government publications. Publi cations marked with an asterisk (*) are not available for distribution.

*Bul. 36. Notes on Irrigation in Connecticut and New Jersey. By C. S. Phelps an E. B. Voorhees. Pp. 64. Price, 10 cents.

Bul. 58. Water Rights on the Missouri River and its Tributaries. By Elwood Mea Pp. 80. Price, 10 cents.

Bul. 60. Abstract of Laws for Acquiring Titles to Water from the Missouri Ri and its Tributaries, with the Legal Forms in Use. Compiled by Elwo Mead. Pp. 77. Price, 10 cents.

Bul. 70. Water-Right Problems of Bear River. By Clarence T. Johnston an Joseph A. Breckons. Pp. 40. Price, 15 cents.

Bul. 73. Irrigation in the Rocky Mountain States. By J. C. Ulrich. Pp. 64. Price 10 cents.

Bul. 81. The use of Water in Irrigation in Wyoming. By B. C. Buffum. Pp. 5 Price, 10 cents.

*Bul. 86. The Use of Water in Irrigation. Report of investigations made in 1899 under the supervision of Elwood Mead, expert in charge, and C. T Johnston, assistant. Pp. 253. Price, 30 cents.

Bul. 87. Irrigation in New Jersey. By Edward B. Voorhees. Pp. 40. Price, 5 cents.

*Bul. 90. Irrigation in Hawaii. By Walter Maxwell. Pp. 48. Price, 10 cents.

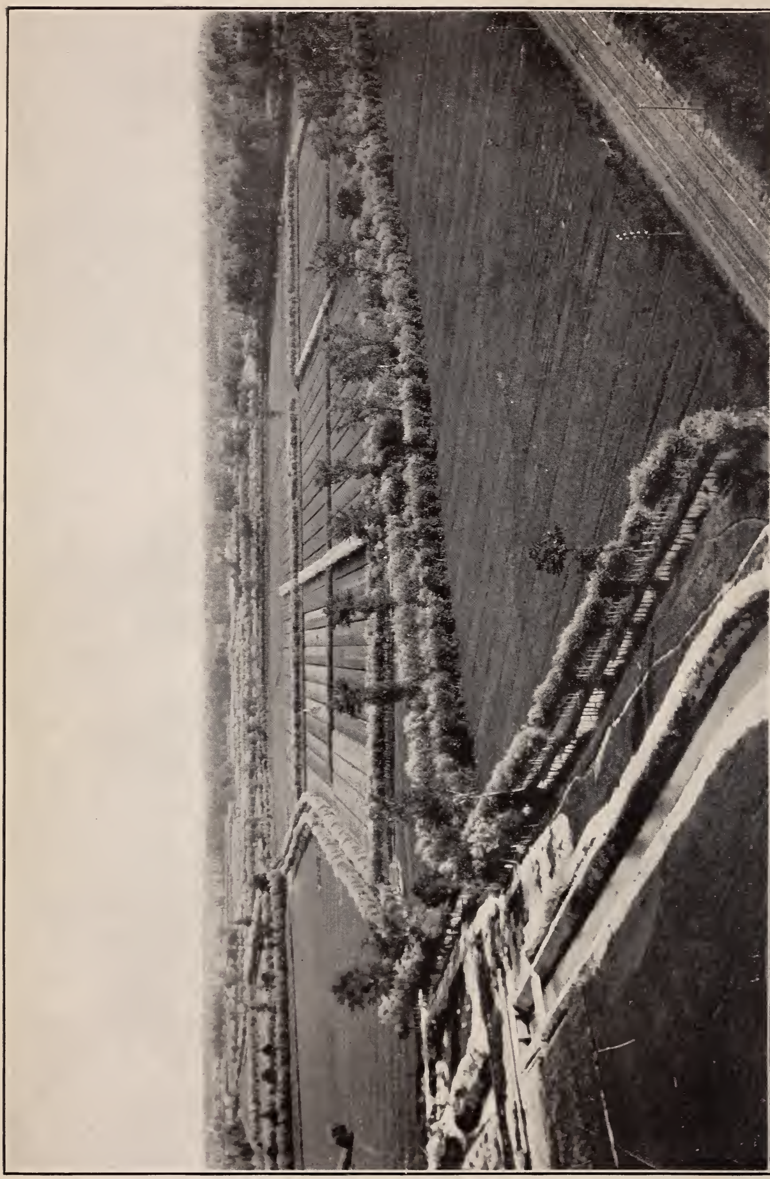
Bul. 92. The Reservoir System of the Cache la Poudre Valley. By E. S. Nettleton Pp. 48. Price, 15 cents.

Bul. 96. Irrigation Laws of the Northwest Territories of Canada and of Wyomin with Discussions by J. S. Dennis, Fred Bond, and J. M. Wilson. Pp. Price, 10 cents.

Bul. 100. Report of Irrigation Investigations in California, under the direction Elwood Mead, assisted by William E. Smythe, Marsden Manson, J. Wilson, Charles D. Marx, Frank Soulé, C. E. Grunsky, Edward M. Bog and James D. Schuyler. Pp. 411. Price, cloth, $1.25; paper, 90 cen

*Bul. 104. The Use of Water in Irrigation. Report of investigations made in 19 under the supervision of Elwood Mead, expert in charge, and C. Johnston, assistant. Pp. 334. Price, 50 cents.

[Continued on third page of cover.]



VIEW OF IRRIGATED LANDS UNDER VETTABBIA CANAL.

Reconstructed canal shown in left-hand corner. Timber-bordered ditches are from springs. Ridged fields in center are marcite meadows.

717

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN NO. 144.

A. C. TRUE, Director.

IRRIGATION IN NORTHERN ITALY.

Part I.

BY

ELWOOD MEAD,

Chief of Irrigation Investigations.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1904.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., May 10, 1904.

Sir: I have the honor to transmit herewith a report on irrigation in northern Italy by Prof. Elwood Mead, chief of irrigation investigations. This work was undertaken in accordance with the law requiring this Office to report "upon the use of irrigation waters at home and abroad," and had for its special object the obtaining of suggestions for the improvement of our own practices—administrative, engineering, and agricultural. This object was kept constantly in view, and, therefore, the report is not a comprehensive treatment of Italian irrigation, but describes only those works and institutions which contain some suggestions which are of value to American irrigators. The report will be divided into three parts, of which this is the first. Its publication as a bulletin of this Office is recommended.

Very respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

PLATES.

TEXT FIGURES.

IRRIGATION IN NORTHERN ITALY—PART I.

CHAPTER I.

INTRODUCTION.

Reasons for a better understanding in the United States of the Italian irrigation system—Features of agricultural engineering included in the investigation—First impressions of the irrigated territory—Extent and physical features of the valley of the Po—Climate and crops—Irrigation laws and practices—Aid extended by the Italian Government in the conduct of these investigations—Laws and reports consulted.

For the past fifty years Italy has been a school of irrigation for the rest of the world. France, Egypt, India, and Australia have sent their ablest engineers and economists to study the system which for many centuries has made northern Italy one of the agricultural storehouses of southern Europe. Their admirable reports, especially those of Capt. Baird Smith and Colonel Moncrieff, have exerted great influence on irrigation practice in the countries for which they were prepared and have been widely read by students of irrigation in the United States; but, as they were written by men who were dealing with conditions differing widely from our own, they do not touch some of our most difficult questions. Especially is this true of the economic as distinguished from the engineering side of irrigation. Besides, the most valuable of these books were written long ago, before modern corporation methods had become an important factor in the extension of irrigation in Italy and before the public supervision of streams, which marked the beginning of the reign of Victor Emmanuel, had become part of the policy of the nation. These changes have brought the legal and administrative features of the irrigation system of Italy into closer resemblance to our own, making a study of this system of great value in solving some of the problems of our arid region.

In the details of irrigation practice it is of interest to know whether Italian canal companies deliver water at the banks of the main canals and let the farmers manage the laterals, or carry it to the margins of the fields where used, and to know whether on a ditch five hundred years old the farmers at the upper end steal water from those at the lower end, as they do in our pioneer communities; or, if they do not, how this most natural and human impulse has been overcome.

In Italy all streams are Government property, and in theory no one is allowed to make diversions from them without permission from the Government. But we need to know whether this public ownership and control is a living fact or a dead theory, as it is in some sections of this country where public ownership is often said to exist, but where streams are diverted at any point and claimed in any amount without regard to rights or interests of existing users or to the public welfare. No available literature tells enough about how titles to water are established to enable students of this question in this country to compare the methods of settling these questions in Italy with our practice of leaving these matters to be fought out in private law suits.

A knowledge of whether the division of water among irrigators is made by time or by volume, of the price irrigators pay for water, of how much they use on different crops, of how seepage losses are lessened and overwatered lands drained in one of the countries where irrigation practice has reached its highest state of efficiency can not fail to have great practical value in this country where tens of thousands of farmers each year begin the cultivation of crops by irrigation. The opportunity to gain this information came in the summer of 1903, when, under the direction of the Office of Experiment Stations, two months were spent by the writer in the valley of the Po.

The work of the Office of Experiment Stations in agricultural engineering made certain other features of European agriculture of much interest, and such time as could be spared was used for observing methods of reclaiming tidal marshes by dikes and drains and of protecting hillside farms from erosion. Some of the stupendous works for draining the low, flat lands at the mouths of the Adda and Po rivers were visited, as were some of the engineering works to protect the hill lands along the Rhine in Germany and the slopes of the Alps and Apennines in northern Italy from washing away. Here, through the aid of embankments, terraces, and drains, farms as steep as any in Pennsylvania, Kentucky, or Georgia, continuously cultivated for many centuries, are as fertile to-day as they were in the beginning. It was reassuring to know that gullies and worn-out fields are not necessary results of cultivation in a broken country, and that our scarred hillsides are simply the outcome of careless and unskillful practice.

THE VALLEY OF THE PO.

From the tower of the cathedral of Milan one looks out over a farming district noted the world over for its fertility and productiveness. When I first saw it the blazing July sun beat down upon it and the air was hot and dry, yet the fields were fresh and green as in the spring. In every direction except to the south the country looked like a vast orchard because of the mulberry trees which dotted the

fields and the brush which bordered the roads and ditches. Wheat is one of the most important crops of this district. It had been harvested; the fields where it had grown had been irrigated; other crops had been planted and were already growing vigorously, irrigation making it possible to grow two crops in the same year, although the season is no longer than in the southern half of the United States.

In one respect the appearance of the country was a surprise. I had thought of Italy as a land of oranges, olives, and grapes, resembling in appearance that around Los Angeles, Fresno, and San José. The irrigated section is not, however, the fruit-growing one. This is farther south and in the hills. The country looked more like that around Greeley and Salt Lake. The desert background was lacking, but there was the same splendid mountain setting made by the snow-covered summits of the Alps. To the south the country was flatter, and the mulberry trees and grain fields gave way to great green stretches of rice fields and meadow lands. Much of the country surrounding Milan is devoted to marcite, a kind of water meadow which produces enormously and helps to make this one of the leading dairy districts of southern Europe.

Two large canals are a part of this cathedral-tower panorama. These, with the multitude of smaller ditches seen in this bird's-eye view, have been described by Hérisson as follows:

> The system of irrigation has nowhere else been carried out to such an extent. As we pass through the Milanese lowlands we can perceive the power of this organization and its effects. Almost every hundred yards we come upon either a canal or a drain. There is not a field but is bathed along at least two sides by clear and running water, brought sometimes from a distance of more than 100 miles. Fertilizing streams intermingle with blocks of cultivated land, which are always beautiful, and even in the dead of winter we may see the mowers cutting down splendid crops of grass. This water which gives to the summer the freshness of the rainy season, can also give to winter the warmth of spring. The mind is overcome with wonder at what the intelligence and energy of the people have accomplished, especially when we consider that Lombardy has always been the battlefield of all Europe and that it has been in the midst of the incessant ravages of war and the continual changes of governments that these prodigious works have been constructed.[a]

The valley of the Po was originally occupied by an arm of the Adriatic Sea. It is 250 miles long, 30 to 100 miles wide, and is bounded and sheltered on three sides by a great mountain horseshoe made by the Alps on the north and west and the Apennines on the south. Near the foothills the country is hilly and broken and the soil in places a coarse gravel not very fertile, but away from the foothills, especially near the Po, the soil has great fertility and the plain is remarkably well suited to the distribution of water. There is slope enough to make it easy to spread water over the fields and to furnish drainage. From Turin to the Adriatic there is not a hill, and many of the large canals run for miles without making a change in direction. In the

---

[a] Rapport sur les Irrigations de la Vallee du Po, Paris, 1881.

eastern part of the valley, especially near the borders of the Adriatic, the country is so flat as to make the rivers almost seem to run uphill. The sediment washed down from the mountains has been deposited here by the Adige and Po rivers until their channels have been built up above the surrounding lands. Here levees are necessary to keep the rivers within their bounds and drains have been dug to carry the water off the adjacent fields. The works required to protect this part of the valley from floods and to reclaim the flat lands along the seacoast rank in magnitude and cost with the irrigation canals on the upper portion of the river in Lombardy and Piedmont. More than half of the irrigated land of Italy is found in these two provinces. They have been called the storehouse of southern Europe and are among the most densely populated in the world, reaching in some places 800 inhabitants to the square mile.

WATER SUPPLY.

The main artery of the valley is the Po. It rises in Mount Viso, about 6,000 feet above the sea. For the first 20 miles it is a mountain torrent, but within 50 miles it changes to a broad stream with a sandy channel which looks not unlike the Platte or Arkansas. Farther down there is another change. The river has scarcely any fall and becomes a broad, sluggish stream and an important highway of commerce.

The rivers which rise in the higher Alps are largely fed from glaciers. They have their floods when the snows are melting and during the autumn rains, April being the month when their supply for irrigation is most likely to be lacking. On several of these rivers floods are a constant menace to irrigation works. Others rise in or flow through lakes which serve as regulators, holding back the floods and warming the glacial water, thus forming an added and valuable feature in the advantages this country presents for irrigated agriculture. The following table gives the minimum, maximum, and mean discharges of the most important of these rivers at or near their mouths:

Discharge of principal Italian rivers.[a]

River.	Discharge in cubic feet per second.		
	Minimum.	Maximum.	Mean.
Adda	636	35,315	7,063
Adige	3,532	88,288	7,769
Dora Baltea	....	70,630	7,593
Dora Riparia	....	17,658	2,013
Mincio	1,236	5,297	2,719
Oglio	1,271	11,301	4,838
Panaro	35	24,403	1,307
Po	7,557	247,205	60,742
Reno	....	40,965	3,355
Secchia	141	27,828	1,483
Sesia	1,413	47,675	2,755
Tanaro	....	60,036	4,697
Taro	....	42,378	1,483
Ticino	1,907	176,575	11,265

[a] Taken from Manual of Engineering by G. Colombo.

The water supply from the Apennines is less abundant and more irregular in its flow than that from the Alps. Ten acres of land are irrigated on the north side of the Po for every one on the south.

In addition to the rivers and lakes there are in some places, notably around Milan, numerous springs which furnish in the aggregate large volumes of water. Some of these springs seem to be fed from the mountain lakes; others are simply natural drains for seepage water coming from the fields and canals on the higher lands.

In many important respects the conditions governing agricultural development in this valley have a surprising similarity to those of the Sacramento Valley, California. Irrigation is the problem in the upper part of both valleys; drainage and flood protection is the problem in the lower parts. While the rainfall in Italy is greater than that in California, crops can be grown in both regions by rainfall alone. The only advantage which Italy possesses over California is in a larger water supply. The soil of California is more fertile, the climate is far superior, and in the range and diversity of products the advantages are all with the Pacific slope. Because of similarity of conditions the methods by which the Italians have drained their wet lands and irrigated their dry ones have a special value to the people of the Pacific slope.

CLIMATE.

Northern Italy has the same latitude as the northern part of the United States. Milan, Turin, and Venice are farther north than St. Paul and Portland. Along the Adriatic there is little difference between the temperature of summer and winter, but in the western part of the irrigated district there is a continental climate with cold winters and long, hot summers. The country along some of the river bottoms looks marvelously like the bottom lands along the Missouri River between Kansas City and St. Louis. There are the same crops and the same weeds. The corn, wheat, and clover fields above where the Cavour Canal crosses the Dora Baltea River look like the fields one sees from the car windows of the Santa Fe Railroad, and this familiar appearance is heightened by the giant poke stalks, blackberry vines, and black-locust brush which grow along the roadsides and in the waste places.

In the vicinities of Milan and Turin the thermometer goes down to zero in winter, up to 100° F. in summer, and the difference between the average temperature of the hottest month of summer and the coldest month of winter is 80° F.

The rainfall records have unusual interest because of the light they throw on the value of irrigation in humid regions. Northern Italy is not arid. The average rainfall of Milan is greater than that of Cincinnati or Omaha, and it is three times that of Denver. Figures 1, 2, and 3 show graphically the average rainfall of Milan for the last

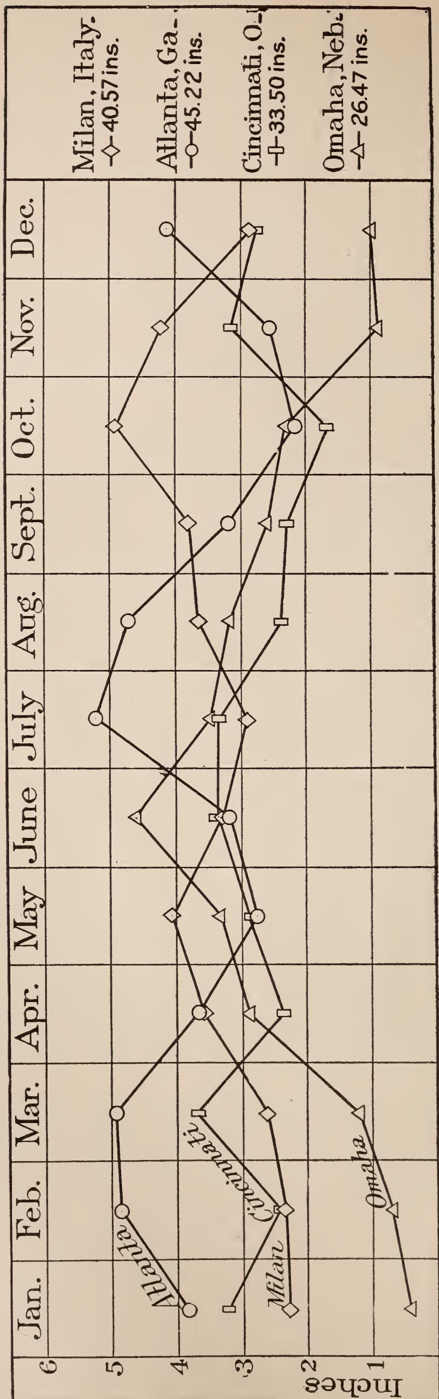


FIG. 1.—Diagram showing the average monthly and the annual rainfall of Milan, Italy, and of three places in the humid portion of the United States.

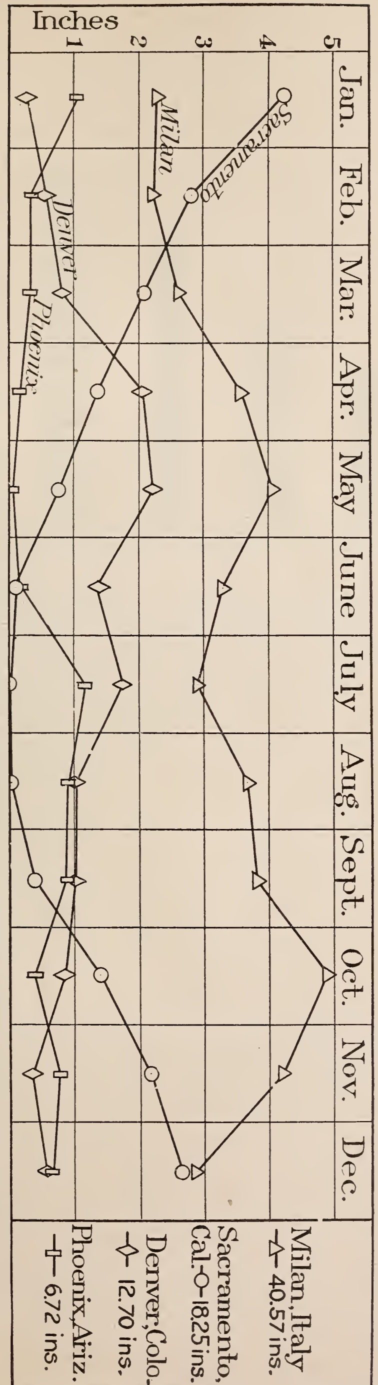


FIG. 2.—Diagram showing the average monthly and the annual rainfall of Milan, Italy, and of three places in the arid portion of the United States.

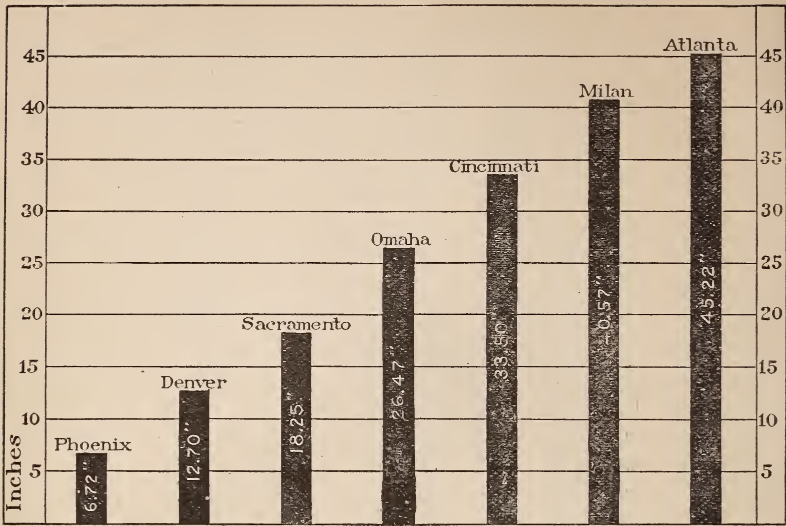


FIG. 3.—Diagram comparing the average annual rainfall of Milan, Italy, with that of six places in the arid and humid portions of the United States.

eighty years and that of a number of places in the United States for fifteen years. It will be seen by studying these diagrams that Milan has a humid climate[a] and is in striking contrast even to Sacramento, where crops are successfully grown by rainfall alone. The rainfall at Milan has been taken for comparison because this city is in the center of the irrigated district. In other parts of the valley the rainfall varies widely, being greater in some places and less in others. In the foothills of the Alps it is excessive. The moisture-laden clouds from the Adriatic when driven against the mountains are condensed, causing at times terrible floods. In some places the average annual rainfall reaches 90 inches. Close to the Alps the average is about 55 inches. In the middle of the valley the average ranges from 30 to 40 inches. South of the Po it falls to 25 inches or less.

CROPS.

Considering the crops grown, the irrigated part of the valley can be divided into three zones. Nearest the mountains, where the country

[a] Professor Taricco, assistant professor of geology in the School of Engineers at Turin, gave the following as the relative amounts of rainfall at Milan and Turin for the four seasons of the year:

Percentage of rainfall by seasons at Turin and Milan.

	Winter.		Spring.		Summer.		Autumn.	
	Turin.	Milan.	Turin.	Milan.	Turin.	Milan.	Turin.	Milan.
Per cent of rainfall	14.7	21.3	26.3	23.9	31.6	23.9	27.4	30.9

is broken and gravelly, the wheat, corn, and clover are varied by orchards and vineyards. Farther down the orchards are replaced by mulberry trees. Still farther down, where the lands have a slight and uniform slope, rice fields and marcite meadows prevail. As the Adriatic is approached, flax and hemp are extensively raised.

IRRIGATION LAWS AND PRACTICES.

While a better understanding of Italian irrigation showed that it had a lesson for the eastern part of the United States, the significance of its teachings for the arid region was not diminished. The observed points of resemblance between their laws and practices and ours grew with a knowledge of the details of different districts. Take the measurement of water as an illustration. In the arid States, irrigators and miners who measure water by the inch employ a direct successor of the Italian oncia. The Cipolletti weir, seen on so many western ditches, was designed by the Italian irrigation engineer whose name it bears. Their canals are built with more care and of more enduring material than ours, but we are beginning to change our practice, and hence a knowledge of what they have done and how they did it will be of great service to us.

It is, however, in the domain of irrigation economics that we have the most to learn from Italy. The laws and institutions which control the diversion of rivers have been the growth of centuries. The fact that they are the result of growth rather than of a prearranged plan brought into effect by legislation, affords another resemblance to our conditions and explains why there is almost as much difference between the irrigation systems of Piedmont and of Lombardy as between those of different arid States. For the purposes of study, and especially for the purposes of comparative study of different systems of supplying water to irrigators, Italy has many advantages. In a few miles along the east and west banks of the Ticino there are canals which combine navigation and irrigation, and irrigation and power; one district manages a large number of private canals, another district operates a larger number of State canals, and a private corporation operates a $6,000,000 system which combines power, irrigation, and drainage. Large areas where water is paid for according to the volume used, adjoin areas where it is paid for according to the area watered, and others where the holders of vested rights get all they want for nothing.

In their leading features the water laws of Italy resemble the codes of Wyoming and Nebraska, the difference being the greater authority possessed by Italian officials and the more effective supervision resulting therefrom.

In the best districts the lack of controversy and friction shows that water can be divided among a multitude of users with justice and

certainty, if the details of this distribution are properly worked out and the regulations imposed rigidly enforced. This is done in Italy. The farmer at the head of a lateral knows that if he attempts to steal water the penalty will be severe, and the farmer at the lower end, not having to police the canal to keep the head gates from being interfered with, goes about his work in peace. The foundation of this efficiency is the capacity of Italian farmers for working together in cooperative organizations. Instead of the management having to deal with each irrigator as an individual with interests antagonistic to the canal and to every other irrigator, as too often happens in the United States, it deals with groups of irrigators who work on a cooperative basis. They buy their water at wholesale and divide it among themselves by time. One cause of fear and jealousy is thus removed. Water is handled in larger volumes, with a saving of water and time to irrigators. To this is added the practice of many of these small associations of paying for water by volume. This makes every farmer study how he can save in expense. It has made him a skillful irrigator, because in lessening waste he gets the benefit of his saving, and it has in course of time brought about a perfection in the rotation and use of water which we must sooner or later emulate if we are to secure the largest and best use of our water resources.

IRRIGATION WORKS.

My first glimpse of Italy's irrigated fields was from the car window of the St. Gothard Railway as we passed through the foothills of the Alps. The little ditches which water the narrow valleys wind their way around the slopes much as they do in the mountains of Utah and Colorado. The head gates and lateral boxes are crude and simple. No provision is made for measuring the water used, as the small quantity taken out does not cause any shortage here or impair the rights below. The simple ditches of the foothill valleys are in striking contrast to the splendid canals which cross the broad plains below, some of which float barges and carry thousands of tons of freight, and run machinery as well as irrigate farms.

Taken together, the large and small canals and ditches of the valley are numbered by thousands. In the irrigated portions of Lombardy and Piedmont the whole country is a network of canals and laterals which cross and recross each other and along which one sees masonry aqueducts, stone-arched bridges, siphons under roads, waste ways, and drains innumerable. The solidity of these structures, taken with their great number, always raised a question as to how much money this development had cost, but there was no way of finding out. All figures of the cost of earlier works have been lost and estimates are of doubtful accuracy. The work has been going on for centuries. There have been changes in political boundaries, in rulers, and in the

policy of the Government toward irrigation. For five hundred years this valley was a battle ground. In these wars the chief cities were repeatedly sacked and burned. Records were lost, and in some cases irrigation works fared badly. In one war the canals in Piedmont were cut to flood the country and embarrass the movements of the Austrian armies. It is certain that the money spent in the past seven hundred years to provide a water supply represents a stupendous outlay. A recent French writer, Ronna,[a] gives the outlay in Lombardy for canals, laterals, drains, and preparing land for water as varying from $200 to $360 an acre. Much of this must be charged to rebuilding and correction of earlier mistakes, both of which have added largely to the original outlay. A large part of the expenditure must also be charged to the perfection with which the fields are prepared for the application of water. The compartments of the rice fields were made perfectly level, the ridges and drains of the marcite meadows were graded as accurately as a railroad yard. Because of this preliminary work the shovel and rubber boots are less important factors in distributing water than with us. In many cases all the irrigator needs to do is to open the head gate and gravity will distribute the water in the right amount and without waste.

AID BY GOVERNMENT OFFICIALS IN CARRYING OUT THESE INVESTIGATIONS.

In a country where canals and ditches are numbered by the thousand and where in places the livelihood of 800 people to the square mile depends upon the water carried, the division of the water supply becomes a matter of supreme importance. It can not be left to chance. It can not be left to the people themselves. Public control is a necessity. To assure to each user his just share of the water supply is a far more difficult problem than it is in the West, where in many places the number of irrigators is less than 20 to the square mile. The success and world-wide fame of Italy's irrigation administration shows that the system is based on correct principles and that it is being carried out by men of ability and executive capacity.

One of the prime objects of this investigation was to ascertain how streams were controlled and divided. For this purpose a visit was made to Rome to meet the officials of the Italian Government who share in the conduct of irrigation affairs. Of these, the department of public works has control of the gauging of streams, the issuance of licenses to divert water, the approval of plans, and, in some instances, the preparation of plans for the construction of new works. The department of agriculture to me was of first interest, because it deals with the questions of chief importance to the farmers and the

[a] Les Irrigations, Paris, 1888, Vol. I, p. 22.

ones which are most closely related to the investigations being carried on by the Office of Experiment Stations. These included studies of irrigation law, methods of distributing and using water, the collection of statistics regarding the areas and values of irrigated lands, and the preparation of reports on irrigation development in the different Italian provinces. The department of finance collects the rentals for water furnished by Government canals and has the administration of canals operated by the Government.

Hon. Hector de Castro, consul-general to Italy, manifested a warm interest in the investigation, and through his aid its purpose was explained to the different departments of the Government.

Widely differing opinions are held as to whether water rights should be attached to the lands or to the ditches or be personal property. The minister of agriculture had prepared for me a statement showing what these limitations are in Italy. The minister of public works gave me a letter to the department inspectors and chief engineers of the bureau of civil engineers of the Kingdom, asking them to facilitate these studies and to place at my disposal the staff and material of their offices. The ministers of agriculture and of public works were most generous in furnishing reports of their departments. The publications named in the bibliography below, supplied by the ministers of these two departments and other interested persons, have been made use of in preparing this report.

Not being able to speak Italian, and expecting to spend much time with the farmers who speak no other language, it was necessary to have an interpreter and desirable to have one who had a knowledge of both engineering and agriculture. Through the assistance of Mr. Smith, acting consul at Milan, such a gentleman was found in Mr. Riccardo Lattes, a civil engineer of Milan. Mr. Lattes speaks English fluently and, having been for several years the representative of American makers of agricultural machinery, knows something of agriculture in both countries.

Two methods of presenting the facts gathered were considered. One was to deal with the subject in a formal manner, discussing in separate chapters the laws, the engineering works, and the agricultural practices of the country. The other was to describe the irrigation works as seen, discuss the conditions as found, and compare these with the works and conditions in our own country, in this way giving the reader something of the impressions created, as well as the facts. Since the object of the study of Italian irrigation was not to prepare a treatise on the subject, but rather to get suggestions for improvement in American practice, the narrative treatment seemed to have advantages over the formal, and it has been adopted. Owing to the length of the report it has been considered best to divide it into three parts. The first will give the studies in Piedmont and in Lombardy

west of the canals from the Adda River; the second will describe the irrigation and drainage works found between the Adda River and the Adriatic Sea, and the third will describe the administration of streams and some of the methods followed by the Government in aiding in the building of both irrigation and drainage works.

BIBLIOGRAPHY.

Ministero di Agricoltura, Industria e Commercio, Direzione Generale dell' Agricoltura. Carta Idrografica d' Italia, Relazioni, Regione Meridionale Adriatica (Hydrographic Survey of Italy, Report Southern Adriatic Region.) Rome: G. Bertero, 1892, pp. 251.

———. Carta Idrografica d' Italia, Arno, Val di Chiana e Serchio, con atlante (Hydrographic Survey of Italy, Arno, Valley of Chiana and Serchio, with maps). Rome: G. Bertero & Co., 1902, pp. 339.

———. Carta Idrografica d' Italia, Arno, Val di Chiana e Serchio, atlante (Hydrographic Survey of Italy, Arno, Valley of Chiana and Serchio, maps). Rome: G. Bertero & Co., 1902.

———. Carta Idrografica d' Italia, Relazioni, Liguria (Hydrographic Survey of Italy, Report Liguria). Rome: G. Bertero, 1894, pp. 244.

———. Carta Idrografica d' Italia, Relazioni, Lombardia (Hydrographic Survey of Italy, Report Lombardy). Rome: G. Bertero, 1896, pp. 565.

———. Carta Idrografica d' Itàlia, Relazioni, Regione Meridionale Mediterranea (Hydrographic Survey of Italy, Report Southern Mediterranean Region). Rome: Eredi Botta, 1890, pp. 555.

———. Carta Idrografica d' Italia, Relazioni, Piemonte (Hydrographic Survey of Italy, Report Piedmont). Rome: G. Bertero, 1895, pp. 499.

———. Carta Idrografica d' Italia, Irrigazione nella Provincia di Novara (Hydrographic Survey of Italy, Irrigation in the Province of Novara). Rome: G. Bertero, 1893, pp. 159.

———. Carta Idrografica d' Italia, Irrigazione del Piemonte, Canali Demaniali d' Irrigazione nelle Provincie di Torino, Novara, Pavia ed Alessandria (Hydrographic Survey of Italy, Irrigation of Piedmont, Government Irrigation Canals in the provinces of Turin, Novara, Pavia, and Alessandria). Rome: G. Bertero & Co., 1902, pp. 91.

———. Carta Idrografica d' Italia, Relazioni, Sicilia (Hydrographic Survey of Italy, Report Sicily). Rome: G. Bertero, 1891, pp. 217.

——— ———. Relazioni, Toscana (Report, Tuscany). Rome: G. Bertero, 1893, pp. 343.

——— ———. Relazioni delle Commissioni Provinciali, Umbria e Marche (Report of the Provincial Commissions on Umbria and Marche). Rome: G. Bertero, 1893, pp. 167.

——— ———. Relazioni, Veneto (Report, Veneto). Rome: Casa Editrice Italiana, 1897, pp. 413.

Ministero dei Lavori Pubblici. Atti della Commissione per lo Studio della Navigazione Interna nella Valle del Po, Relazione Generale (del Presidente), con 8 Allegati e 23 Tavole (Proceedings of the Commission for the Study of Interior Navigation in the Valley of the Po, General Report of the President, with 8 Appendices and 23 Maps). Rome: Camera dei Deputati, 1903, pp. 393.

——— ———. Relazione Prima, Canali e Fiumi di Friulana e Trevisana Navigazione, con 3 Allegati e 27 Tavole (First Report, Navigation Canals and Rivers of Friulana and Trevisana, with 3 Appendices and 27 Maps). Rome: Camera dei Deputati, 1903, pp. 116.

Ministero dei Lavori Pubblici. Relazione Seconda, Canali e Fiumi di Padovana e Vicentina Navigazione, con 6 Allegati e 20 Tavole (Second Report, Navigation Canals and Rivers of Padova and Vicentina, with 6 Appendices and 20 Maps). Rome: Camera dei Deputati, 1903, pp. 71.

——— ———. Relazione Terza, Da Venezia al Po—Fiumi e Canali del Polesine e del Veronese, con 7 Allegati e 23 Tavole (Third Report, From Venice to the Po—Rivers and Canals of Polesina and Verona, with 7 Appendices and 23 Maps). Rome: Camera dei Deputati, 1903, pp. 159.

——— ———. Relazione Quarta, Il Po da Torino al Mare, con 11 Allegati e 7 Tavole (Fourth Report, The Po from Turin to the Sea, with 11 Appendices and 7 Maps). Rome: Camera dei Deputati, 1903, pp. 137.

——— ———. Relazione Quinta, Canali e Fiumi Navigabili nella Bassa Pianura Emiliana, con 7 Allegati e 33 Tavole (Fifth Report, Navigable Canals and Rivers in the Lower Emilian Plain, with 7 Appendices and 33 Maps). Rome: Camera dei Deputati, 1903, pp. 262.

——— ———. Relazione Sesta, Fiume Mincio e Lago di Garda, con 1 Allegato e 25 Tavole (Sixth Report, Mincio River and Lake Garda, with 1 Appendix and 25 Maps). Rome: Camera dei Deputati, 1903, pp. 380.

——— ———. Relazione Settima, Fiumi, Canali e Laghi Navigabili di Lombardia, con 5 Allegati e 30 Tavole (Seventh Report, Navigable Rivers, Canals, and Lakes of Lombardy, with 5 Appendices and 30 Maps). Rome: Camera dei Deputati, 1903, pp. 222.

——— ———. Relazione Ottava, Cenni sulla Navigazione Interna all' Estero, con 2 Tavole (Eighth Report, History of Internal Navigation in Foreign Countries, with 2 Maps). Rome: Camera dei Deputati, 1903, pp. 37.

Reale Osservatorio di Brera in Milano. Andamento Annuale e Diurno della Pioggia nel Clima di Milano, per E. Pini (Annual and Daily Rainfall in Milan, by E. Pini). Milan: Ulrico Hoepli, 1891, pp. 67.

Ministero dei Lavori Pubblici. Legge e Regolamento sulle Derivazioni di Acque Pubbliche (Law and Regulations for Diversions of Public Waters). Rome: Eredi Botta, 1885, pp. 56.

Regio Decreto che modifica il comma 1 e 2 dell' art. 6 del regolamento del 26 Novembre 1893, n. 710, per la derivazione di acque pubbliche—19 Dicembre 1895 (Royal Decree of December 19, 1895, amending Parts 1 and 2 of Art. 6 of the Regulations of November 26, 1893, No. 710, for the diversion of public water).

Ministero dei Lavori Pubblici. Atti della Commissione Centrale Permanente per l' Esame Preventivo delle Domande di Derivazione delle Acque Pubbliche, Istituita con Regio Decreto 11 Giugno 1899, Anno 1899 (Proceedings of the Permanent Central Commission for the Preliminary Examination of Applications for the Diversion of Public Waters, Created by Royal decree of June 11, 1899, Year 1899). Rome: Editrice Italiana, 1900, pp. 226.

——— ———. Year 1900. Rome: Editrice Italiana, 1901, pp. 374.

——— ———. Year 1901. Rome: Unione Cooperativa Editrice, 1903, pp. 223.

——— ———. Year 1902. Rome: Unione Cooperativa Editrice, 1903, pp. 215.

Ministero dei Lavori Pubblici. Relazione della Commissione Nominata con Decreto 16 Agosto 1898 dei Tre Ministri dei Lavori Pubblici, delle Finanze e dell' Agricoltura, per lo Studio del Futuro Regime delle Concessioni delle Acque Pubbliche in Relazione coi Nuovi Bisogni dello Stato e dell' Industria Nazionale, con Verbali e Documenti annessi (Report of the Commission appointed by the decree of August 16, 1898, by the Three Ministries of Public Works, Finance, and Agriculture, for the Investigation of the Future System of Granting Concessions of Public Waters, in Relation to the New Needs of the State and of National Industry, with Minutes and Documents attached). Rome: G. Bertero, 1898, pp. 233

Decreto e Regolamento per la Gestione, Manutenzione e Custodia dei Canali Demaniali, 9 Febbraio 1893, Numero 166 (Decrees and Regulations for the Operation, Maintenance, and Custody of Government Canals, February 9, 1893, No. 166). Turin: Gazzetta del Popolo, 1893, pp. 43.

Decreto che Modifica il Testo del Regolamento per la Gestione, Manutenzione e Custodia dei Canali d' Irrigazione e Forza Motrice Appartenenti al Patrimonio dello Stato e Tabella di Riparto del Personale di Custodia, 1 Marzo 1896, Num. 83 (Decree amending the text of the regulations for the operation, maintenance, and custody of irrigation canals and water power belonging to the State, with apportionment of custodians to provinces, March 1, 1896, No. 83). Turin: Gazzetta del Popolo, 1896, pp. 8.

Legge che Modifica alcuni articoli dell' altra legge del 20 Marzo 1865, n. 2248, sulle opere pubbliche, 30 Marzo 1893 (Law of March 30, 1893, amending several articles of the law of March 20, 1865, No. 2248, on Public Works).

Commissione nominata dal Ministero dei Lavori Pubblici, con Decreto 5 Novembre 1893, N. 8857, per lo studio e proposta di un riparto delle acque dell' Adda fra i canali Muzza, Retorto e Cassano, Relazione della (Report of the Commission appointed by the Minister of Public Works, by the decree of November 5, 1893, No. 8857, for the investigation of and recommendation for distribution of the waters of the Adda among the Muzza, Retorto, and Cassano canals). Milan: P. B. Bellini, 1898, pp. 387 and 89.

———. Allegato XX (Appendix XX to the preceding). Mantova: A. Mondovi e Fig., 1898, pp. 214.

———. Allegato XXI (Appendix XXI to the preceding). Mantova: G. Mondovi, 1898, pp. 475.

Pestalozza, Alessandro, e Valentini, Carlo. Sistemazione del deflusso delle acque del Lago di Como, con 19 Allegati e 16 Tavole (Control of the Discharge of Water from Lake Como, with 19 Appendices and 16 Maps). Milan: Ulrico Hoepli, 1899, pp. 231.

Ministero dei Lavori Pubblici, Direzione Generale delle Opere Idrauliche. Relazione sul Progetto di Massima dell' Acquedotto Pugliese, compilato dal Regio Ufficio Speciale del Genio Civile, in data 20 Ottobre 1902, Fascicolo I, Testo (Report of Surveys for Pugliese Aqueduct, compiled by the Special Royal Office of Civil Engineers, dated October 20, 1902, Vol. I, Text). Rome: Editrice Italiana, 1903, pp. 58.

——— ———. Fascicolo II, Prospetti Diversi (Vol. II, Various Projects). Rome: Editrice Italiana, 1903, pp. 107.

——— ———. Fascicolo III, Disegni (Vol. III, Maps and Drawings). Rome: Editrice Italiana, 1903, maps 16.

———. Ufficio Speciale Amministrativo per l' Acquedotto Pugliese, Legge, Regolamento e Capitolato per la Costruzione e l' Esercizio dell' Acquedotto Pugliese (Special Administrative Office for Pugliese Aqueduct—Laws, Regulations, and Contracts for the Construction and Operation of the Pugliese Aqueduct). Rome: Editrice Italiana, 1903, pp. 181.

Ufficio Tecnico di Finanza. Informazioni sulle Dispense d' Acqua dei Canali Irrigatori (Information regarding the Distribution of Water from Irrigation Canals). MS.

Ufficio Tecnico di Finanza di Milano. Canale Muzza, Dati Tecnico (Muzza Canal, Technical Data). MS.

Leggi e Decreti sul Riscatto dei Canali Cavour, 16 Giugno, 6, 9 e 11 Luglio 1874, Nri. 2002, 2004, 2018 e 2020, Serie 2 (Laws and Decrees for the Acquirement of the Cavour Canals, June 16, July 6, 9, and 11, 1874). Turin: Gazzetta del Popolo, 1874, pp. 75.

Leggi complementari sul Canale Cavour sul Cavo Gazelli presso Chivasso sul Canale di Cigliano e sul Canale Quintino Sella, 23 Luglio 1881, 7 Marzo 1886, 6 Febbraio 1887, 2 Giugno 1887 e 6 Agosto 1893, Nri. 329, 3714, 4313, 4530, Serie 3 e 446 (Supplementary Laws regarding the Cavour Canal, the Gazelli Canal heading at Chivasso, the Cigliano Canal, and the Quintino Sella Canal, July 23, 1881, March 7, 1886, February 6, 1887, June 2, 1887, and August 6, 1893). Turin: Gazzetta del Popolo, 1894, pp. 10.

Decreto e Regolamento per l' Amministrazione Economica del Canale Cavour e degli altri Canali che vi sono annessi, 27 Aprile 1890, Num. 6861, Serie 3 (Decrees and Regulations for the Economic Administration of the Cavour Canal and other Canals connected therewith, April 27, 1890). Turin: Gazzetta del Popolo, 1890, pp. 23.

Legge riguardante i Consorzi per l' Irrigazione in data 25 Maggio 1873, Numero 1387, Serie 2 (Law regarding Irrigation Associations, dated May 25, 1873). Turin: Gazzetta del Popolo, 1887, pp. 7.

Leggi, Decreti e Regolamento sull' Ordinamento dei Consorzi d' Irrigazione, 28 Febbraio 1886, Nri. 3731, 3732, e 3733, Serie 3 (Laws, Decrees, and Regulations for the Organization of Irrigation Associations). Turin: Gazzetta del Popolo, 1887, pp. 24.

Regio Decreto che modifica l' articolo 18 del regolamento 28 Febbraio 1886, n. 3733 (serie 3ª) per l' esecuzione delle leggi sui consorzi d' irrigazione, 30 Gennaio 1890 (Royal decree of January 30, 1890, amending article 18 of the regulations of February 28, 1886, for the execution of laws regarding irrigation associations).

Legge portante disposizioni complementari alla legge 28 Febbraio 1886, n. 3732 (serie 3ª), sui consorzi di irrigazione e di derivazione di acque per uso industriale, 11 Maggio 1890 (Law of May 11, 1890, carrying supplementary provisions to the law of February 28, 1886, regarding associations for irrigation and diversion of water for industrial purposes).

Legge che fissa le norme e le disposizioni secondo le quali debbono essere ordinati i consorzi di derivazione e di uso delle acque a scopo industriale sia volontari che obbligatori, 2 Febbraio 1888, Numero 5192, Serie 3ª (Law fixing the rules and regulations according to which shall be organized associations for the diversion and use of water for industrial purposes, either voluntary or obligatory, February 2, 1888). Turin: Gazzetta del Popolo, 1888, pp. 7.

Decreto e regolamento per l' esecuzione della legge 2 Febbraio 1888, n. 5192, concernente i consorzi di derivazione e di uso delle acque a scopo industriale, 24 Giugno 1888, Numero 5497, Serie 3ª (Decrees and regulations for the execution of the law of February 2, 1888, concerning associations for the diversion and use of water for industrial purposes, June 24, 1888). Turin: Gazzetta del Popolo, 1888, pp. 12.

Comprensorio di Corbetta. Testo unico del regolamento del, Edizione di Agosto del 1900 (Corbetta Association, Codification of the regulations of the, edition of August, 1900). Corbetta: L. Radaelli, 1900, pp. 42.

———. Memoria pella liquidazione dell' acquisto di servitù di passaggio d' acqua in base ai patti ed alle condizioni del regolamento del comprensorio (Memorandum relating to settlements for the acquirement of rights of way by contract in accordance with the conditions of the regulations of the association).

———. Convenzione fra il, e la Società Italiana per condotte d' acqua relativa ai cavi emuntori e fugatore (Agreement between the Corbetta Association and the Italian Society of Aqueducts relative to waste and drainage canals).

———. Convenzione per affitto d' acqua del Canale Villoresi pel seiennio 1898–1903 (Agreement for rental of water from the Villoresi Canal, for the six years 1898–1903).

Consorzio d' Irrigazione delle Roggie Comuna ed Unite di Crema, Statuto pel, approvato 19 Luglio 1890, n. 1732 (Irrigation Association of the Comuna and Unite Canal, of Crema, Statutes of, approved July 19, 1890). Crema: Ercole Rolleri, 1896, pp. 30.

———. Regolamento di Amministrazione del, approvato 22 Dicembre 1900, n. 4175 (Regulations for the administration of, approved December 22, 1900). Crema: Vincenzo Moretti, 1900, pp. 31 and 32.

Consorzio per l' Incremento dell' Irrigazione nel Territorio Cremonese, Statuto del, depositato 23 Settembre 1882 (Association for the Increase of Irrigation in the Cremonese Territory, Statutes of, filed September 23, 1882).

———. Capitolato per affitti di acque (Rules for the rental of water).

———. Tariffa dei canoni annuali per l' affitto delle acque distribuite dai canali del (Tariffs for the rental of water distributed by the canals of the).

Pestalozza, Alessandro. Note e Considerazioni sopra il Progetto del Canale di irrigazione dell' Alto Agro Veronese (Notes and Observations upon the plan for an irrigation canal for the Northern Veronese Lands). Verona: G. Franchini, 1883, pp. 21.

Ferrari, Ciro. Le Condizioni del Consorzio Alto Agro Veronese (The Condition of the Northern Verona Lands Association). Verona: G. Civelli, 1893, pp. 16.

Consorzio Alto Agro Veronese. Delle Condizioni Economico-Finanziarie del (Economic-Financial Conditions of the Northern Verona Lands Association). Verona: G. Civelli, 1894, pp. 17.

———. Relazione della Commissione nominata dai Portatori di Obbligazioni del, 31 Marzo 1894 (Report of the Commission appointed by the Bondholders of the, March 31, 1894). Verona: G. Civelli, 1894, pp. 30.

———. Relazione del Consiglio di Amministrazione ai (Report of the Council of Administration of the). Verona: G. Civelli, 1900, pp. 9.

———. Relazione dell' Operato dal Consiglio di Amministrazione del, nel triennio 1900–1902 (Report of the work of the Council of Administration of the, for the three years 1900–1902). Verona: G. Civelli, 1903, pp. 4.

———. Consorzio d' Irrigazione dell', Statuto e Regolamento (Irrigation Association of the, Statutes and regulations of). Verona: Antonio Gurisatti, 1901, pp. 27.

———. Memoria del (Memorial of the). Verona: G. Civelli, 1903, pp. 5.

L' Associazione d' Irrigazione dell' Agro all' Ovest della Sesia, Capitolato e Statuto per, pel secondo trentennio a partire dal 1 Gennaio 1884 (Irrigation Association of the Lands West of the Sesia, Contracts and Statutes of, for the second 30 years, beginning January 1, 1884). Vercelli: Guidetti Francesco, 1882, pp. 58, 56, 24, 16, 11.

Comprensorio di Vittuone. Specchietto Finanziario, 1902–1903 (Vittuone Association, Financial Statement, 1902–1903).

Società Italiana per Condotte d' Acqua. Avviso (Notice—regarding rental of water). Milan: Capriolo e Massimino, 1902.

Consorzio Idraulico Alto Tartaro, Tione ed Influenti, Regolamento del, 25 Agosto 1885 (Hydraulic Association of the Upper Tartaro, Tione and Tributaries, Regulations of the, August 25, 1885). Verona: G. Franchini, 1885, pp. 34.

Consorzio VI Presa (Padova). Relazione approvata 19 Gennaio 1899 (Report approved January 19, 1899). Padova: L. Penada, 1899, pp. 29.

La Vettabbia. MS. (History of Vettabbia Canal.)

Canale Villoresi, e Fiume Ticino. Tabella delle Portate del (Table of the discharge of the Villoresi Canal and of the Ticino River). Milan: Capriolo e Massimino, 1902.

Società Italiana per Condotte d' Acqua. Brevi Cenni sul Canale Villoresi (Brief Sketch of the Villoresi Canal). Rome: Eredi Botta, 1885, pp. 18.

Tribunale Civile di Milano. Causa Civile formale della Utenza della Roggia Retorto contro la Società Linificio e Canapificio Nazionale et al. (Users of the Retorto Canal v. National Flax and Hemp Society et al.). Crema: F. Ferre, 1901, pp. 112.

———. Note d' udienza (Note of hearing in the above case). Milan: M. Bellinzaghi, pp. 18.

———. Aggiunta alla Comparsa conclusionale della Utenza della Roggia Retorto (Addition to the final statement of the users of the Retorto Canal in the above suit). Crema: Plausi & Cattaneo, 1903, pp. 142.

Disposizione di un prato a marcita (Arrangement of a marcite meadow). MS.

Celli, A., e Menozzi, A. La Depurazione Agricola delle Acque di Fognatura di Milano (The Agricultural Purification of the Sewage Water of Milan). Modena: Società Tipografica, 1902, pp. 191.

Leggi sulle opere di bonificazione di laghi, stagni, paludi e terreni paludosi, 25 Giugno 1882 e 4 Luglio 1886, Numeri 869 e 3962, Serie 3 (Laws regarding works of reclamation of lakes, swamps, and wet lands, June 25, 1882, and July 4, 1886). Turin: Gazzetta del Popolo, 1886, pp. 24.

Decreto e regolamento per l' esecuzione delle leggi 25 Giugno 1882 e 4 Luglio 1886 sulla bonificazione delle paludi e dei terreni paludosi, 7 Settembre 1887, Num. 4963, Serie 3 (Decrees and regulations for the execution of the laws of June 25, 1882, and July 4, 1886, regarding reclamation of swamps and wet lands, September 7, 1887). Turin: Gazzetta del Popolo, 1887, pp. 54.

Decreto e regolamento per le bonificazioni delle paludi e dei terreni paludosi, 21 Ottobre 1900, N. 409 (Decrees and regulations for the reclamation of swamps and wet lands, October 21, 1900). Turin: Gazzetta del Popolo, 1901, pp. 72.

Legge che porta modificazioni ed aggiunte alle vigenti leggi sulle bonificazioni delle paludi e dei terreni paludosi, 18 Giugno 1899, N. 236 (Law of June 18, 1899, amending and adding to the laws regarding reclamation of swamps and wet lands). Turin: Gazzetta del Popolo, 1899, pp. 15.

Decreto e regolamento sulla costituzione dei consorzi per le opere idrauliche di seconda categoria, 9 Febbraio 1888, Numero 5231, Serie 3 (Decrees and regulations for the organization of associations for hydraulic works of the second class, February 9, 1888). Turin: Gazzetta del Popolo, 1888, pp. 8.

Legge n. 304—Modificazioni alle disposizioni concernenti le opere idrauliche di 3ª, 4ª e 5ª categoria, 7 Luglio 1902 (Law amending the provisions regarding hydraulic works of the 3rd, 4th, and 5th classes, July 7, 1902).

Legge n. 333—Riparto delle spese per le opere di bonifica dichiarate di 1ª categoria, 7 Luglio 1902 (Apportionment of expenses for hydraulic works of the first class, July 7, 1902).

Ministero dei Lavori Pubblici. Testo Unico della legge sulle bonificazioni delle paludi e dei terreni paludosi, approvato con R. D. 22 Marzo 1900, n. 195 (Codification of the laws relating to reclamation of swamps and wet lands, approved by Royal decree, March 22, 1900). Rome: Tipo-Litografia del Genio Civile, 1900, pp. 37 and tables.

———. Regolamento per la esecuzione del testo unico della legge sulle bonificazioni delle paludi e dei terreni paludosi, 22 Marzo 1900, n. 195, approvato con R. D. 21 Ottobre 1900, n. 409 (Regulations for the execution of the preceding codification, approved by Royal decree October 21, 1900). Rome: Tipo-Litografia del Genio Civile, 1901, pp. 71.

Ufficio Tecnico della Provincia di Cremona. Studio di Massima per la bonifica del territorio inferiore Cremonese-Mantovano (Investigation of methods for the reclamation of the lower Cremona-Mantova territory). Cremona: Leoni, 1896, pp. 155.

——— ———. Allegati (Appendices). Cremona: Leoni, 1896.

Carlo, Marchi. Cenni storici del Polesine, Provincia di Rovigo (Historical sketch of the Polesina, Province of Rovigo). MS.

Baccarini, Alfredo. Sul Compimento delle opere di bonificazione e sulla definitiva regolazione delle acque nelle maremme Toscane (Report upon completion of reclamation works and upon final regulation of the water in the sea marshes of Tuscany). Rome: E. Sinimberghi, 1873, pp. 237 and tables.

Amenduni, Giovanni. Sulle opere di bonificazione della plaga litoranea dell' agro Romano che comprende le paludi e gli stagni di Ostia, Porto, Maccarese e delle terre vallive di Stracciacappa, Baccano, Pantano, Lago dei Tartari (Reclamation works in the coast country of Rome, etc.). Rome: Eredi Botta, 1884, pp. 274.

——— ———. Tavole (Maps). Rome: Eredi Botta, 1884.

Legge sulla istituzione di casse di depositi e prestiti per tutto il regno e modo di amministrarle, 17 Maggio 1863, Numero 1270 (Law for the organization of banks of deposit and loan for the entire Kingdom and manner of their administration, May 17, 1863). Turin: Gazzetta del Popolo, 1878, pp. 8.

Pastore, Giovanni. Manuale dell' utente delle acque d' irrigazione, ossia formole pratiche maggiormente in uso per calcolare la portata delle bocche di derivazione più comuni e relative tavole (Manual for the use of irrigation water, with formulas used in calculating the discharges of diversion gates, and tables of equivalents). Mortara: Botto, 1894, pp. 85.

Nazzani, I. Trattato di Idraulica Pratica (Treatise on Hydraulic Practice). Milan: Ulrico Hoepli, 1886, pp. 441.

Colombo, G. Manuale dell' Ingegnere Civile e Industriale (Manual of Civil and Industrial Engineering). Milan: Ulrico Hoepli, 1902, pp. 423.

Chapter II.

IRRIGATION IN LOMBARDY.

Three typical canal systems in this province: The Naviglio Grande, and the Villoresi and Vettabbia canals—Methods employed in measuring and distributing water—Preparing land for irrigation—Manner of applying water to crops—Cost and duty of water—Fontanili or springs used in irrigation.

Lombardy, because of its central location in the valley and the historic and agricultural importance of its irrigation works, was the most appropriate place to begin this study, and Milan, the chief commercial city of Italy and the railroad center of the valley, was a convenient starting place. There was another reason for making Milan the starting point. Speaking of its rapid growth and prosperity, a recent writer said: "Milan, like Venice, owes everything to water." Its use in irrigation has brought enormous returns from the surrounding land, its use for power is making Lombardy the manufacturing center of Italy, and its use in canals for navigation has connected the city with both the mountains and the sea, bringing to its people cheap building material, cheap fuel, and cheap food.

The plan of the investigation was to spend most of the time in the field to learn from actual observation and inquiry how the canals were operated and how water was divided, and to ascertain what crops were grown and the methods used by farmers in applying water. Such inspection can not be made hastily, and there was time for personal visits to only a few canals in the province. The best way seemed to be to select certain typical ones and use those to illustrate the entire system. After conferring with the Government engineers and with the superintendents of a number of canals having offices in Milan, it was decided that three canals would fairly illustrate both the agricultural and engineering features of irrigation in Lombardy. The three chosen were the Naviglio Grande, the Villoresi, and the Vettabbia. Each of these belongs to a different class with respect to its ownership and operation. The Naviglio Grande belongs to the Government and is used for both irrigation and navigation. The Villoresi is a modern corporation canal which furnishes water to customers for irrigation and for the operation of important power plants. The Vettabbia is managed as a cooperative enterprise by the irrigators who live under it.

THE NAVIGLIO GRANDE—A GOVERNMENT CANAL USED FOR NAVIGATION, IRRIGATION, AND POWER.

The Naviglio Grande (Plates I, II, and III) is the largest of three Government canals entering Milan. The Martesana Canal on the east connects the city with the Adda River; the magnificent canal of Pavia, one of the great public works with which Napoleon endowed Italy, connects the city on the south with the Ticino and the Po. The Naviglio Grande is the waterway to the west and unites the city with the Ticino River and the quarries, vineyards, and factories around Lake Maggiore. All three canals are connected at Milan by the Naviglio Interno, a circular canal 3.5 miles long which occupies the moat of the ancient city and makes it possible to deliver cargoes from one canal to the others and to different parts of the city.

All of these artificial waterways are of ancient origin. The Martesana Canal was constructed under the direction of the Duke Sforza I in 1457. The canal connecting Pavia with Milan was begun about the middle of the fourteenth century, but at that time it was used for irrigation only. The improvements which made it navigable were begun by order of Napoleon in 1805 and completed in 1819. The Naviglio Grande is the oldest of the three and is historically the most interesting. For more than seven hundred years it has been a highway of commerce, as it was begun in 1177. It was nearly a hundred years before the canal reached Milan and was connected with the moat of the city in 1257. It is supposed to have been begun by the monks, because only the nobles and religious orders had at that time the means required for carrying out such enterprises. One fact connected with the completion of this canal has a special interest to engineers. The locks which connect it with the moat of the ancient city were probably the earliest structures of this kind used in navigation, and according to trustworthy tradition were designed and constructed by the great engineer-painter, Leonardo da Vinci.

The present engineer of the Naviglio Grande, Giavana Grillo, kindly made arrangements for a trip through the canal by boat. Accompanied by Engineer Grillo and the superintendent of the first section of the canal, we started at the head and spent a day floating past the towns, factories, and fertile fields which border the canal, stopping wherever there was anything of interest to be studied. From Milan to the head of the canal we traveled by rail to Castana, and from there by carriage to Tornaventa, a little manufacturing town where there is a 4,000-horsepower electrical plant equipped with American machinery.

This railway trip was through irrigated farms. The fields were dotted with mulberry trees, showing that the growing and feeding of silkworms is an important source of income to the farmers. In some places they bordered the fields; in others they were planted in rows varying from 40 to 100 feet apart and from 20 to 100 feet apart in the

rows. There seemed to be no uniformity in the plan of planting or in the treatment the trees received. The indifference regarding the plan of planting probably arises from the fact that the trees seem to cause little injury to crops. Nearly the whole of the top is removed in the spring when the leaves are being fed, so that the trees cause scarcely any shade in the early part of the season. The tops are always kept low and small for convenience in picking the leaves. So far as could be observed, the yields of corn and clover were as great in the fields where there were mulberry trees as in those where there was none.

Everywhere in Lombardy much land is given over to trees and brush. Nearly all roads have a brush border. The fields are separated by rows of trees, and the banks of ditches and canals are lined with them. Where the right of way of the railway was not otherwise used, it was nearly always covered with a dense growth of acacia. The reason for this is the need of fuel. There are no coal deposits in Italy and both wood and coal are expensive, and the high brush which grows along these roadsides and ditches is cut down every few years and the fagots stacked away in barns and outbuildings like grain and straw, furnishing the farmers fuel for both cooking and heating.

Above the railway station at Castana the wagon road crosses the highest canal line. We traveled for some distance past land farmed without irrigation. In the irrigated portion of America irrigation and aridity are always associated, and the contrast between the barrenness above the ditches and the productiveness below them is one of the most striking and interesting features of our irrigation development. It is otherwise in Italy, and one soon gets rid of the idea that irrigation is a feature of agriculture only where crops can not be grown without it. The fields above the ditches were being cultivated in the same way as those below, and the same crops were being grown. Although the sun was intensely hot and the roads white with dust, the grass which grew along the roadside above the ditch was as green and fresh as one would be likely to find at the same season of the year in Indiana or Illinois. The clover and corn fields looked as well as they would in soil no more fertile in either of those two States. In the clover fields the first crop had been cut and the second was well advanced. The corn crop would have been considered a poor yield in the Mississippi Valley, but the land was not suited to growing corn. The fields whose only moisture had come from rains had what would have been considered average crops in the United States, but seen directly in contrast with the luxuriant growth and beautiful green of the corn and clover fields below the ditches, they showed what a factor in production irrigation can be made.

The head of the Naviglio Grande at Tornavento is in a narrow valley where the river winds between high, steep bluffs, from the tops of which there is a beautiful view of the country and river valley.

The distance from Milan is 31 miles. From Tornavento, the head, to Buffalora, 13 miles below, the canal skirts the river valley, then it leaves the river and turns eastward across the plain. These first 13 miles of the canal show that it was built at a time when hydraulic engineering was in its infancy. The easiest way to get rid of excessive grades was to lengthen the canal by making it more crooked, and this was done. The same cause probably accounts for the great irregularities of both breadth and depth. It varies in width from 75 to 165 feet, and in depth from 4.5 feet to 15 feet. The grades are not less erratic, ranging from almost a level in a section 2.5 miles in length near the bridge of San Christofero to a fall of 8 feet to the mile in the first 3 miles. The excessive grade at the head is now being corrected.

The most important structures connected with the canal are the dam and retaining walls at the head. This dam is 918.5 feet in length and varies in breadth from 31 to 58 feet. The greatest part of the structure is concrete, partly held in place by piles and horizontal beams of wood. Over this mass of masonry and concrete a pavement of cut stone has been placed, very closely fitted and bound together with iron dowels. The dam extends diagonally upstream, but does not reach entirely across, about 215 feet of the channel of the river on the opposite side from the canal being left open, and the dam itself is submerged at all seasons, except extreme low water. The stability of this dam is shown by the fact that it has stood for two hundred years, although buffeted at times by tremendous floods. Both sides of the canal at the head are protected by heavy walls of granite masonry, the wall on the upstream side being vertical and on the lower side inclined at an angle of 30 degrees. The bottom for some distance is paved with large granite blocks doweled together.

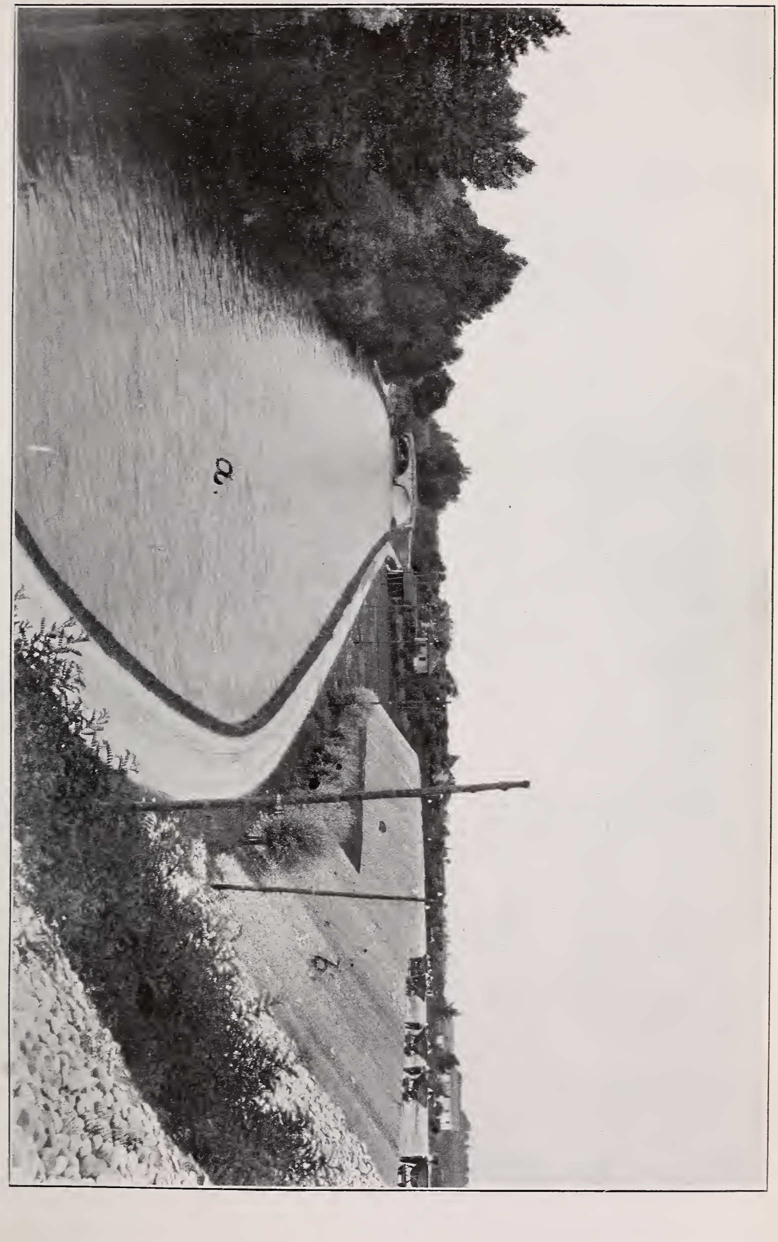
The discharge of the Ticino varies widely in different years, having reached 176,000 cubic feet per second. In 1868 a flood submerged the entire valley at the head gate, doing great damage to the country. On the day of my visit the river was carrying about 35,000 cubic feet of water per second. Between 3,000 and 4,000 cubic feet per second of this was entering the canal. It has a right to only 2,224 cubic feet of water per second, of which 212 cubic feet per second has to be delivered in Milan; 2,012 cubic feet per second is used for irrigation and power or lost through seepage. Therefore, nearly one-half of the water entering the head was being turned back into the river through waste ways. The canal has no head gates on account of its use in navigation and this has made the regulation of the supply during floods a serious problem to those who operate the canal. To accomplish this a large number of waste ways have been constructed in the first 5 miles of the canal. There are in all 185 openings in these waste ways, the gates being of wood set in masonry structures. Each of these structures has from three to six gates which are about 6 feet high and from 3.28 to 6.56

feet wide. Nearly all are lifted with an iron crowbar used as a lever, the end being thrust into holes in the gate stems. The water master said that gates 1 meter (3.28 feet) wide were most satisfactory, as the wider ones are hard to operate when the canal is full of water. During flood seasons as high as 40,000 cubic feet per second has entered the head of the canal. The permanent gates are unequal to the regulation of such volumes of water and can not be operated quick enough in case of sudden storm. To meet such emergencies there is another opening in the canal near the head which seems to be as effective as it is primitive. It is a channel leading back to the river considerably wider than the canal and excavated to the level of its bottom. Across this a row of posts are placed 8 feet apart. To these posts are bolted two timbers, the lower one being about 8 inches and the upper one 5 feet above the bottom. These timbers make a continuous support for a lining of willow brush 6 or 7 feet long placed against it, and thick enough to furnish a substantial backing for a strip of burlap which runs along in front of it and is tacked through the brush to the stringers at the back (Pl. I). The pressure of the water holds the burlap close against the brush, which has sufficient stiffness to support it. Although the water contains practically no sediment, this burlap made an almost water-tight lining, there being scarcely any leakage. When a flood comes the opening of this waste way is a matter of only a few seconds. Beginning at the upper end the burlap is torn off and the water rushes through, carrying the brush away with it.

All these features of the canal will soon be changed. The first 5 miles are being reconstructed to utilize the heavy fall in this distance for power purposes and to regulate the quantity of water entering the canal by a head gate. The new head gate will be about a quarter of a mile from the river. It will be of masonry and of the most substantial character. In connection with the head gate there will be a series of locks for the entrance of boats and for their discharge into the old canal. The grade of the old canal for the first 6 miles varies from 4.5 to 8 feet per mile. The grade of the new canal will be 1.06 feet per mile. The gain in grade gives a drop of 27 feet, which will furnish 6,000 effective horsepower. Plate II gives a view of the old and the new canal about 4 miles below the head. These improvements are being made by a company to which the Government granted a franchise to run for sixty years. It pays the Government a tax of 60 cents a year for each horsepower, and at the expiration of the franchise turns the entire work over to the Government. The estimated cost of the work is $720,000. This, with the $3,600 yearly rental, is the price paid by the company to the Government for the concession. The prospects are, however, that the enterprise will be highly profitable, as the company has already contracted the greater part of its

WASTE WAY NEAR HEAD OF NAVIGLIO GRANDE.

Canal with brush and burlap retaining wall in center of picture. Trench for foundation of permanent wasteway in foreground.



VIEW OF NAVIGLIO GRANDE, WHERE BEING REBUILT.

a, Old canal; *b*, embankment of new canal.

power at from $30 to $40 per horsepower per year. The disposal of all the available power, which is practically assured, will mean a gross income of more than $180,000 a year, of which the estimated net profit, excluding accident, is $100,000 a year, the principal items of expense being the 6 per cent interest on the original investment and the Government rental.

MEASUREMENT OF WATER.

To those familiar with disputes over the quantity of water delivered and used, due to our absence of adequate methods of measurement, the history of the Naviglio Grande for the first one hundred years is most instructive. It was a continuous record of quarrels over the water supply and the methods of dividing it.

The canal was built without any well-defined regulations as to how much water each customer was to receive and without any established system of measurement. Irrigators were permitted to take water as they pleased, and used it without restraint. Out of this combination of ignorance and neglect there grew up interests which exercised rights really belonging to the Government, and which afterwards opposed persistently any effort at regulation.

In the earlier years rights to its water were given away in the most reckless manner to reward private services, or to purchase the support of nobles or the church. Another abuse was farming out the rentals of the canal, which sacrificed the farmers to increase the revenues of those who might control the water supply. The first systematic attempt at measurement was made in 1376 and the unit employed was the quantity of water required to drive a mill wheel and was defined as the flow through a rectangular orifice 4 inches high and 18 inches wide, with the bottom of the orifice 8 inches above the bottom of the canal. As the canal in some places is 15 feet deep and in other places only 4.5 feet, there was a wide variation in the volume discharged. Seventy years later the extravagant grants of rights to water in the canal led the reigning duke of Milan to annul all rights to water in all of the rivers, canals, and streams of the Milanese territory. This sweeping abrogation of private rights threatened to bring on a revolution and led to its being limited to rivers and canals which were the property of the State, and even this, in the case of the Naviglio Grande, was never imposed.

In 1503 the canal passed under the control of King Louis XII of France, who attempted to lessen the disorder prevailing by the creation of a commission to improve the methods of measuring and delivering water from the canal. This commission made an order requiring that the bottom of all measuring gates be placed 1.92 feet above the bottom of the canal; that every orifice should be cut in a single stone slab no more than 3 inches thick; that all should have a uniform

height of 4 inches; and that between the orifice and the outlet gate in the canal bank there should be a chamber 15 feet long. The form of measuring box now in use was the design of Engineer Giacomo Soldati.

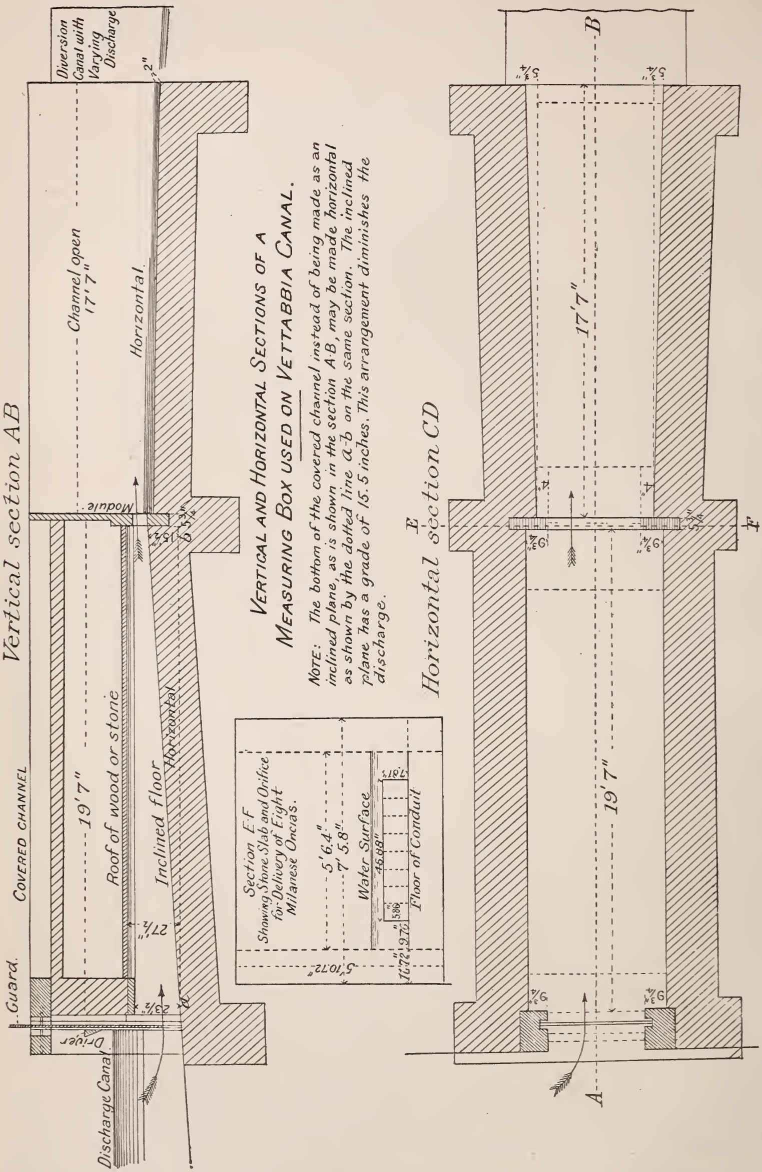


Fig. 4.—Vertical and horizontal sections of a measuring box used on Vettabbia Canal.

Soldati's efforts to secure the acceptance of his design lasted more than five years. So strong was the opposition that it was only after a commission of ten of the most eminent lawyers and engineers of

Milan had approved his device that it could be put into use, and its final adoption found him reduced to poverty, deserted by his clients, and embittered by persecution.

Every measuring box seen along the canal was of the pattern recommended by Soldati. The unit of measurement is the quantity of water which flows freely under the influence of the pressure through a rectangular opening, having a height of 4 Italian inches (7.86 United States inches), a breadth of 3 Italian inches (5.72 United States inches), and a constant pressure above the upper edge of the orifice of 2 Italian inches (3.93 United States inches). In all those observed a wooden regulating gate working in grooves in masonry was set in the side of the canal. The gate stem was locked in front with a key carried only by the water master, who raises or lowers the gate in order to maintain the required pressure on the orifice below. The diagram (fig. 4) gives the details of one of the measuring boxes examined.

SOME FEATURES OF THE CANAL'S MANAGEMENT.

All the sediment coming from the mountains is deposited in Lake Maggiore. The river was perfectly clear, fish could be distinctly seen in the bottom of the canal where the water was 6 feet deep, and although the clear water made the canal an attractive swimming pool for numerous groups of boys, and caused scores of washerwomen (Pl. III) to line its banks in every village, it has certain drawbacks for the canal management. Clear water offers no check to seepage losses, which in places are heavy. Measurements showed a loss of 141 cubic feet of water per second in the first 4 miles. This rate continued throughout the entire length of the canal would absorb about one-fourth of the supply. Clear water is also favorable to the rapid growth of aquatic plants, and the removal of water grass is one of the problems of the Naviglio Grande. In a number of places men on boats were cutting the grass with long-handled scythes. When cut the grass floated off down the canal and doubtless caused more or less trouble by choking up measuring boxes. For two hundred years it has been the practice to clean the canal in March, a time when water is least needed by irrigators. At this time a temporary dam is placed at the head to shut out the water. Ordinarily 12 people operate the canal; but during flood seasons sometimes 100 men are employed.

Not much was learned of the income of the Government from this canal; but it was manifest that it is not a money-making property and it is doubtful if it pays operating expenses. Navigation is free. Many of the rights to water in the canal entitle their owners to its free delivery, the Government getting nothing for the water or for its expenses in distributing it. Although the Government at one time abrogated the ancient vested rights, it has been compelled to recognize

them, and the reckless grants of water made in the early years of the canal's history are now bonanzas to owners who control them, but a burden to the taxpayers. Irrigators who are not so favored are inclined to regard these ancient rights as a nuisance because, as a rule, they result neither in improvement to the canal nor in benefit to any water users who help to support it.

Rates for the water rented vary greatly, some being based on ancient privileges. As a rule the rentals for old rights are much lower than those charged under agreements recently made. What little water the Government is able to dispose of without restrictions is delivered to farmers for $180 per cubic foot per second for the entire year, or for $140 per cubic foot per second for summer irrigation. There are over 100 ancient rights to water for mills and power, most of which are free. No perpetual rights to water are now being sold, the usual limit for franchises or concessions being thirty years. The annual charge for water for power purposes is very low.

The canal is classified by the Government as a navigation canal, and is under the charge of the department of public works instead of the treasury department, as would be the case if it were classified as an irrigation work.

The utilization of water power is adding to the population and prosperity of the country along the upper end of this canal.

There are few places in the world, perhaps, where the growing influence of water for industrial uses is more apparent than in the valley of the Ticino, and especially along the upper half of the Naviglio Grande, and certainly few places in the world where the industrial changes which are increasing the struggle for extended and intensive use of the water are more evident.

THE VILLORESI CANAL—A MODERN CORPORATION ENTERPRISE FURNISHING WATER FOR IRRIGATION AND POWER AT ANNUAL RENTALS.

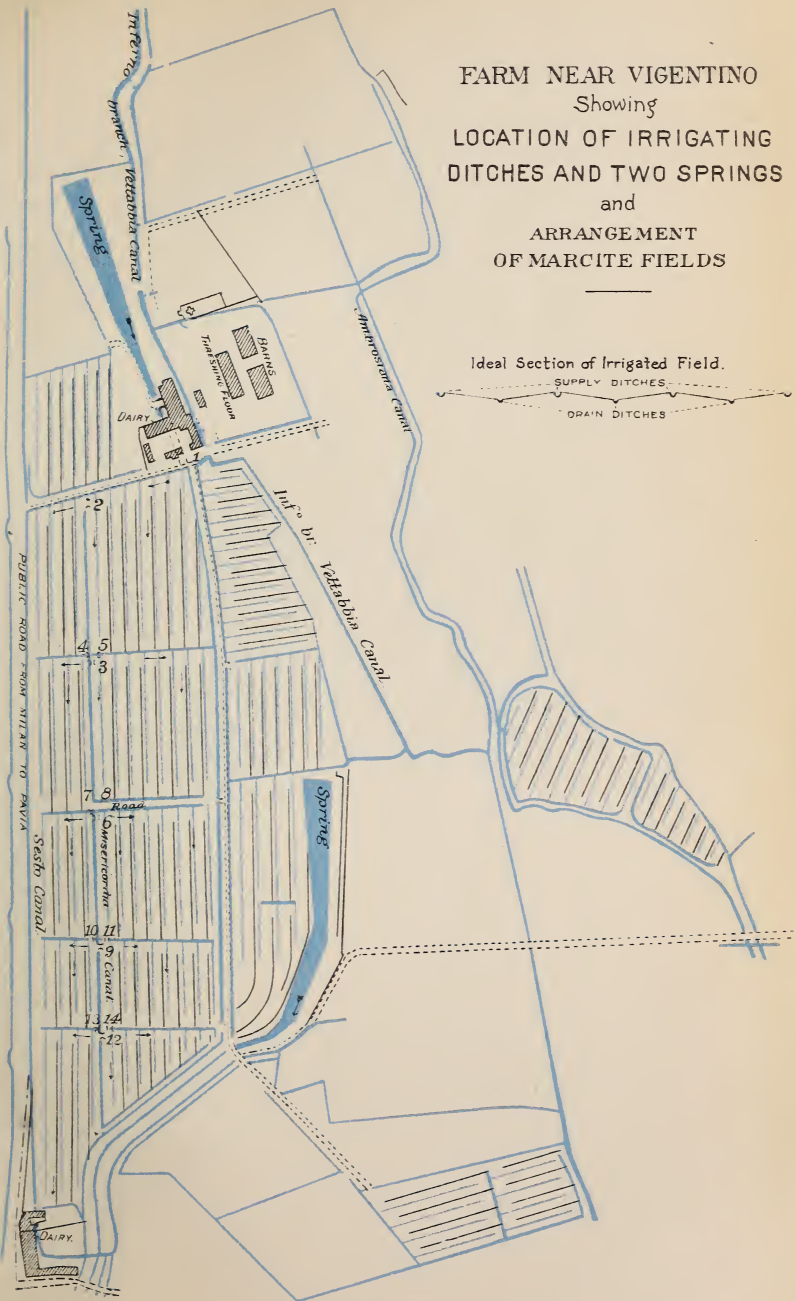
In 1850, an engineer named Villoresi began the survey of a high-line canal which was to start at Lake Maggiore and wind its way among the foothills which border that body of water until it reached the plain north of the Po, and cover all the valley lands north of Milan between the Ticino and Adda rivers. Its construction would have involved the crossing of many miles of broken country where the outlay would have been enormous. Men with money did not look upon it with favor. There was another drawback to the enterprise. It was not new; it had been talked about for centuries. Six hundred years before, the channel of a great ditch had been cut part way around the river bluffs and then abandoned. The land it was to have watered needed to be irrigated, and there was water in the river for this purpose. Thinking of the crops which had been ruined by drought, farmers

FIG. 1.—SCENE ON NAVIGLIO GRANDE.

Road on right is the towpath. Figures in foreground are washerwomen.

FIG. 2.—SCENE ON NAVIGLIO GRANDE.

Farm village bordering the canal and arched masonry bridges crossing it.


FARM NEAR VIGENTINO
Showing
LOCATION OF IRRIGATING
DITCHES AND TWO SPRINGS
and
ARRANGEMENT
OF MARCITE FIELDS
Ideal Section of Irrigated Field.
SUPPLY DITCHES
DRAIN DITCHES
Inferno branch, Vettabbia Canal
Spring
BARNS
THRESHING FLOOR
DAIRY
Ambrosiana Canal
Infº br. Vettabbia Canal
PUBLIC ROAD FROM MILAN TO PAVIA
Sesto Canal
Road
Misericordia
Canal
Spring
DAIRY.

named the abandoned canal "The Canal of the Lost Bread." Villoresi had to overcome the fears caused by this failure, but he was a man of means and determination and clung to the project. It took eighteen years to obtain from the Government a concession for the canal and secure the special partnership act required to provide the large amount of capital which the work would cost. The city of Milan offered to aid the enterprise by a gift of $1,000,000, but even this did not secure sufficient subscriptions to the capital stock to enable Villoresi to begin the construction, and he died in 1880 without seeing the work begun, after spending thirty years of his life and all his fortune, disappointed and poor.

Following Villoresi's death the city of Milan offered to undertake the work as a municipal enterprise if the farmers would agree to purchase 353 cubic feet of water per second. This they would not do, and the city abandoned the enterprise. There were two causes for these failures. Farmers were required to sign in advance perpetual contracts to take water, which would have been equivalent to placing perpetual mortgages upon their farms. Farmers feel that there is hazard enough in signing such contracts after the canals are built, but in this case they were asked to sign them in advance of construction. Scores of canal companies in the West have encountered the same hesitation. It has delayed the construction of many canals and caused the financial failure of many more. The other reason for the failure to secure capital was the opposition of the owners of prior rights in the Ticino River below the point where the Villoresi was to be taken out. Altogether these amount to 4,237 cubic feet per second. As the river carries less than 2,000 cubic feet per second at low water, it was manifest that there would be a shortage for some canal. The holders of the prior rights feared the new canal would lessen their supply or subject them to anxiety and expense in preventing this. Arrangements had to be made which would remove the fears of the holders of prior rights before the Government would issue a concession for the new canal. This was done by building the head works in such a way that they would let flow down stream the entire amount belonging to the holders of prior rights below before any water could be taken into the Villoresi. As a further guarantee the Government undertook to maintain a gauge rod in the river above the canal and to see that the Villoresi's gates were closed until more than 4,237 cubic feet per second belonging to the other ditches was running in the stream.

The only time when there is a shortage in the water in the Villoresi is in April, and the water which runs to waste in the flood season would supply this many times over. To relieve this shortage the Government has given the canal company a right to convert Lake Maggiore into a storage reservoir. As this lake has an area of over 150,000

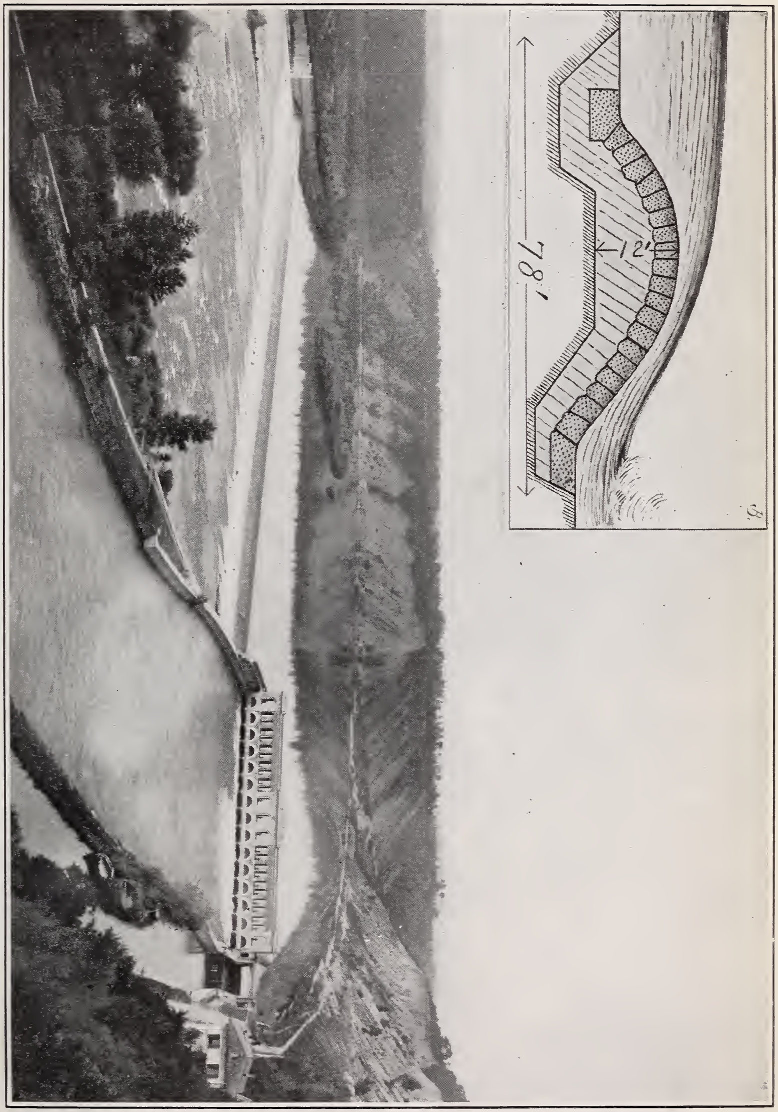
acres, a dam 1 foot high would furnish an acre-foot of water for every acre of land now irrigated under the canal. It is proposed, however, to build a dam several feet high in order to secure an additional water supply for power purposes. Work on the dam was begun this year.

After a third of a century of fruitless effort a corporation known as the Italian Society for Aqueducts offered to build the canal without any advance contracts with farmers if the city of Milan would give a bonus of $400,000, payable in ten annual installments. The city did this and the Villoresi Canal, one of the monumental irrigation works of the world, was begun. No irrigation work in America equals it in the strength and perfection of its engineering features. From the dam at the head to the smallest measuring box on the laterals the work has been planned and carried out with a finish and careful consideration of the service it is to render that made its inspection a matter of continued pleasure.

Although the canal has the name, it is not the original project of Villoresi. Instead of starting at the outlet of Lake Maggiore, its head gate is 15 miles below, being halfway between the lake and the head gate of the Naviglio Grande. Like the latter canal, it runs along the bluff east of the river until it reaches the summit, when it makes a sharp turn to the east and crosses the plain about 9 miles north of Milan, watering all the country between the canal and the city.

The head gate is located just below an abrupt bend in the river where the entire force of the current is thrown against it. Looking down at the headworks from the top of the bluff, it was manifest that irrigation engineers in Italy have been given a freer hand to spend money in making their structures enduring than has thus far been accorded engineers in America. Plate V shows this view. To meet the requirements of the Government the headworks had to embrace a number of structures. The dam interrupted the passage of boats, hence a navigation canal with suitable locks had to be provided. A weir had to be constructed which would guarantee the automatic delivery of the water belonging to the holders of prior rights below. The company furnishes 282 cubic feet of water per second to a private canal, and has both a power and an irrigation canal of its own.

The figure in the upper left-hand corner of Plate V shows in outline the cross section of the dam, which is built of concrete faced with cut granite masonry. It is 950 feet long, 78 feet wide, and 12 feet high, protected at the foot by a masonry platform which extends downstream 50 feet. Both ends of the dam are protected by masonry wing walls. The one on the shore opposite the head gate is 164 feet long, while the one on the canal side is over 2,000 feet long and serves as a division wall between the canal and the river. At the upper end it is of solid masonry; at the lower end it broadens out into an earth embankment with a masonry retaining wall, as shown in the illustration.



VIEW OF HEAD GATE OF VILLORESI CANAL.

B, in upper left-hand corner, is cross section of diversion dam.

The head gate is a 2-story structure, the lower story being of granite and the upper of brick. It is 220 feet long, 42 feet high, and 20 feet wide. There are 30 openings closed by gates 5 feet wide and 11.5 feet high, with sills 9 feet below the top of the dam. They are designed to admit 6,709 cubic feet of water per second when the water is even with the top of the dam. Of this, 4,237 cubic feet per second must go to the lower users along the Ticino and 2,472 cubic feet per second is available for irrigation. The gates are operated independently of each other by screws worked from the second floor.

The navigation canal for permitting boats to go around the dam is between the head gate and the river bank. It is 26 feet wide on the bottom, 10 feet deep, and 1,640 feet long. The main canal for 2,000 feet down from the head gate is 220 feet wide and 10 feet deep. At this point there is a set of regulating works built around a large basin of trapezoidal shape into which both the main canal and the navigation canal enter. On the borders of this basin are placed—

(1) The weir for measuring the water supplying the prior rights.

(2) The navigation channel, provided with suitable locks, for letting boats back into the river.

(3) The head gate for the water of the private canal belonging to the Visconti family.

(4) The head gate of the irrigation canal.

(5) The head gate of the power canal built to utilize part of the water belonging to the prior rights.

This basin and the canal above, having a total area of 73,200 square yards, is lined with cobblestones to a depth of 8 inches, set in concrete cement varying in thickness from 8 to 15 inches.

The measuring weir over which flows the water for the prior rights below is 236 feet long and the water drops over this 15 feet, the force being broken by a deep basin having a bed of cobblestones.

The locks through which boats return to the Ticino are the largest in Italy. The lower gates are 25 feet high and the water in the locks has a rise and fall of 19 feet. The navigation canal below the basin is 33 feet wide and almost a mile long.

There are no diversions of water between the head of the Villoresi and the head of the Naviglio Grande, a distance of 15 miles, in which the river has a fall of 165 feet. Only a small part of this water is needed for navigation. One-half of it could be carried down to the head of the Naviglio Grande in a separate canal and used for developing power. These considerations led the Villoresi Canal Company to construct a power canal below its irrigation canal, starting where the water falls over the weir (15 feet below the grade of the irrigation canal). This industrial canal carries 2,224 cubic feet of water per second. It runs parallel to the Villoresi to Vizzola where there is a fall of 92 feet and where an electrical power plant has been constructed with a capacity of 23,000 theoretical horsepower of which

19,000 is now being developed and sold throughout this region for the operation of numerous factories. From the drop at Vizzola another power ditch, extending to the head of the Naviglio Grande, is being built. A large factory at this point, now operating by steam, will be run by water power when the ditch is completed.

With these two drops the Villoresi will utilize 131 feet of the fall between the head gates of the two canals. This supplemental plant will generate 5,000 horsepower, and 3,000 horsepower is now being furnished by drops along the irrigation works, so the company will soon be selling the enormous total of 31,000 horsepower, making this one of the principal sources of its income.

The regulating gates which turn the water from the basin into the irrigation branch of the Villoresi Canal are three stories high. In the lowest story are six iron gates having a clear width of 7.5 feet each and a clear height of 9.8 feet. They are operated from the second story. The third story is used as a wagon bridge and towpath for the navigation canal.

Some idea of the size of the headworks of this canal may be gathered from the amount of material used in their construction. The temporary works—cofferdams, dikes, etc.—cost $70,000; 380,000 cubic yards of earth were moved and 45,000 cubic yards of cement were employed in paving the canal and basin; and 26,200 cubic yards of stonework, 2,100 cubic yards of brickwork, 4,200 cubic yards of hewn granite, 95,600 cubic yards of cobblestones, 4,800 cubic yards of rough stone, 358 tons of iron, and 500,000 feet B. M. of timber went into these structures.

For the first 10 miles the canal runs along the river bluff, which is high and steep and in many places of coarse gravel formation, making the construction of a waterway difficult and expensive. In this part of the canal the bottom width is 36 feet, the depth 10 feet, and the grade 1.32 feet to the mile. The slope of the sides is 1 to 1.25. The normal discharge of this part of the canal is 1,666 cubic feet per second, which is increased at times to 2,300 cubic feet per second. The construction of a single irrigation canal would have been much simpler, but the matter was complicated by building a short distance below it the power canal to carry 2,224 cubic feet per second. In one place this involved the cutting of a channel 84 feet wide along a bluff where the slope is 1 foot vertical to 1.75 feet horizontal.

It was not the original intention to line either the power or the irrigation canal, but when the clear water of the Ticino was turned in the gravel channel leaked like a sieve and lining was a necessity. Not only here but throughout the greater part of the entire canal the bottom of this lining is a well-beaten bed of concrete, 4 to 8 inches thick, placed 12 inches below the grade line of the canal and covered with a foot of sand and gravel. It is buried in this manner to protect it from

the action of frost in winter. The sides are paved with cobblestones laid in cement, the side lining being from 8 to 15 inches thick and extending up 8 feet from the bottom. Above this the sides are paved with cobblestones laid dry.

At Castelnovata, near the fourth mile, a steep bluff requires a retaining wall 918 feet long and 88.5 feet high, containing in all 524,000 cubic yards of masonry. At Tornavento is another retaining wall 32 feet high, containing 3,934 cubic yards of masonry. This wall is of interest to engineers because it is built on an earth foundation.

In the 10 miles of hillside canal 120 cubic yards of material was excavated for every linear yard of canal. In all, 2,181,150 cubic yards of earth were moved, 120,060 square yards of concrete lining were put in the bottom, and 149,373 square yards of cobblestones on the sides. The bridges on this part of the canal are of iron, of one pattern, 62 feet long, placed 26 feet above the bottom of the canal. In the construction of each 225 tons of iron was used.

After the canal reaches the summit of the bluff and starts across the plain it is built about half in excavation and half in embankment. The

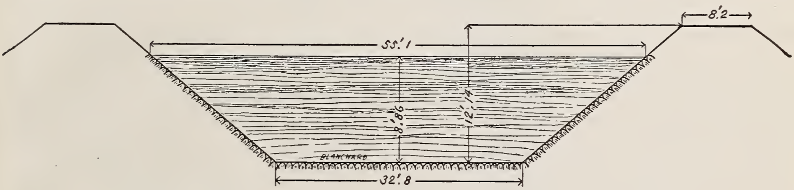


Fig. 5.—Cross section of Villoresi Canal at head of Parabiago branch.

mean grade is 9.6 inches to the mile and the slope of the banks 1 to 1.5. The embankments are 10 feet wide on top. At the upper end of the section the canal is 40 feet wide on the bottom and carries 10 feet of water. It gradually diminishes in size, until near the Adda it is only a small lateral. Figure 5 shows the dimensions of the canal and the paving of the bottom near where the Parabiago lateral heads.

In the first 20 miles of the plain section the canal is crossed by 24 roads and 1 railroad. Brick and stone bridges, 10 to 30 feet wide and supported by 3 arches each, serve for these crossings. Seven public and private streams are crossed. The canal is carried over the Olona River on a masonry aqueduct supported by 3 stone arches. Several creeks pass under the canal by means of inverted siphons. In the construction of this 20 miles the following material was handled:

1,316,550 cubic yards of earth moved, or an average of 37.4 cubic yards per linear yard.
13,500 cubic yards of cement and stone masonry.
10,800 cubic yards of brickwork.
460 cubic yards of stonework.
16,500 cubic yards of concrete.
10,000 cubic yards of dry masonry.

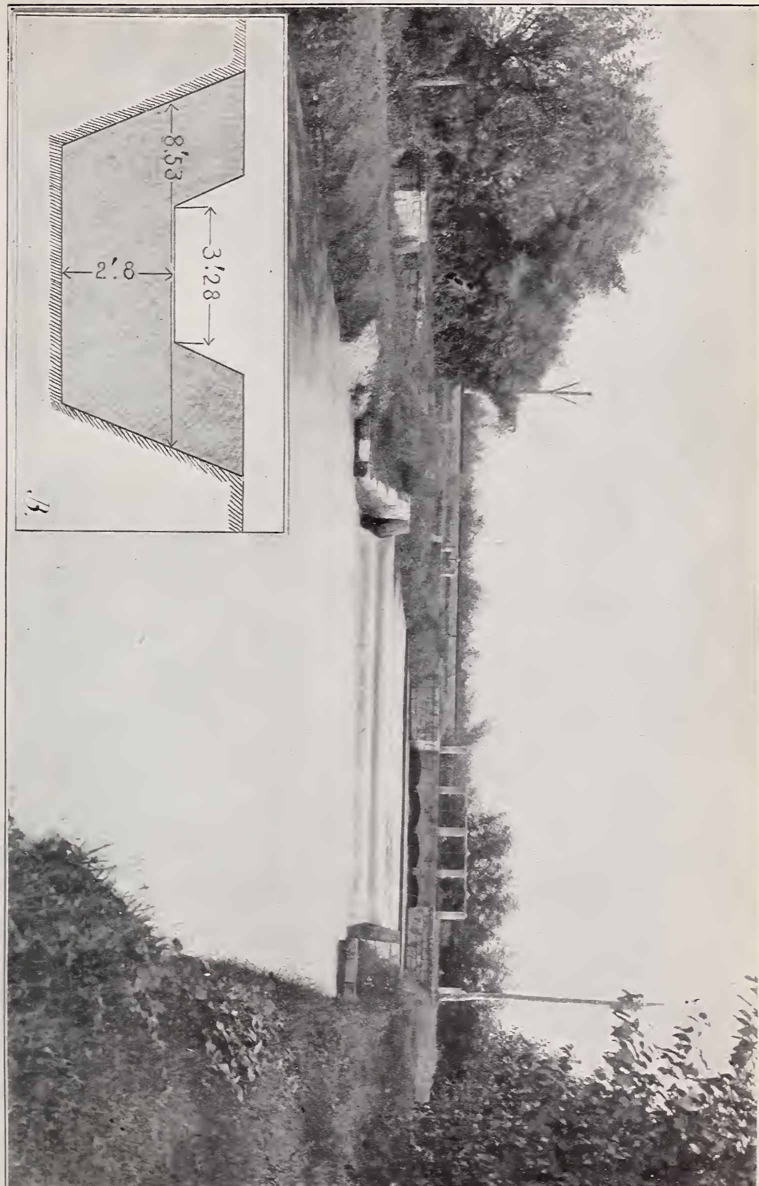
The head gates of 17 distributing canals are located along this 20-mile section. The smallest takes 10 cubic feet per second and the largest 353 cubic feet per second. With one exception the irrigators under each of these lateral canals have united in an association which attends to the delivery of water from such lateral. The only difference in the lateral which is an exception is that it furnishes water to four associations. These secondary canals have an aggregate length of 75 miles. There are altogether over 600 bridges, siphons, and drops along this canal. The 3,000 horsepower generated at these drops is sold to various manufacturing establishments.

The lateral ditches under the Villoresi were built with more care than is bestowed on such works in America. There are no abrupt bends; grades were closely followed, and where gravel strata are crossed the laterals are cemented. Plate VII, figure 1, shows the head gate and measuring weir at the head of one lateral. The gate of iron works in masonry grooves. The basin above the weir is large enough to check the velocity of approach and is paved and cemented. The weir is of cast iron set in masonry. Accuracy in measuring water to the lateral was made possible and a just division along the lateral was insured by giving each farmer the whole volume for the part of each week corresponding to his share of the money payment. The division boxes along the lateral had frameworks of granite slabs, one of the quarries furnishing a granitic schist which splits almost like slate. All the lateral boxes on the entire canal are of standard patterns, are put in by the canal company, and are paid for by the farmers, the charge for each box in place in the laterals being $22.

WATER MEASUREMENT.

The chief engineer of the Villoresi Canal was Cæsare Cipolletti, the inventor of the weir which bears his name and which is coming so largely into use in Western irrigation. Accurate water measurement on an extensive system like this is indispensable. To divide the flow of the main canal among the numerous secondary canals requires this, and the problem becomes even more important when the distribution extends to the multitude of boxes along the laterals. The Cipolletti weir on the Villoresi takes the place of the oncia of Soldati on the Naviglio. Plate VI shows a view of one of these weirs with its regulator in the Parabiago branch of the main canal, which supplies in turn two large laterals. This weir measures 164 cubic feet of water per second, which supplies three minor associations of farmers.

Plate VII, figure 1, shows the construction of one of the weirs leading from a secondary canal into a farmer's lateral: *a* shows the cement paving of the secondary canal, *b* the gate leading into the lateral, and *c* the location of the weir.



MEASURING WEIR AT HEAD OF PARABIAGO BRANCH OF VILLORESI CANAL.

B, Section of weir shown in Pl. VII, fig. 1.

FIG. 1.—HEAD GATE AND MEASURING WEIR ON LATERAL FROM VILLORESI CANAL.
a, Paving of canal; *b*, stone posts at sides of gate; *c*, weir.

FIG. 2.—UNION OF AN IRRIGATION AND A DRAIN DITCH.
a, Irrigation ditch; *b*, drain ditch.

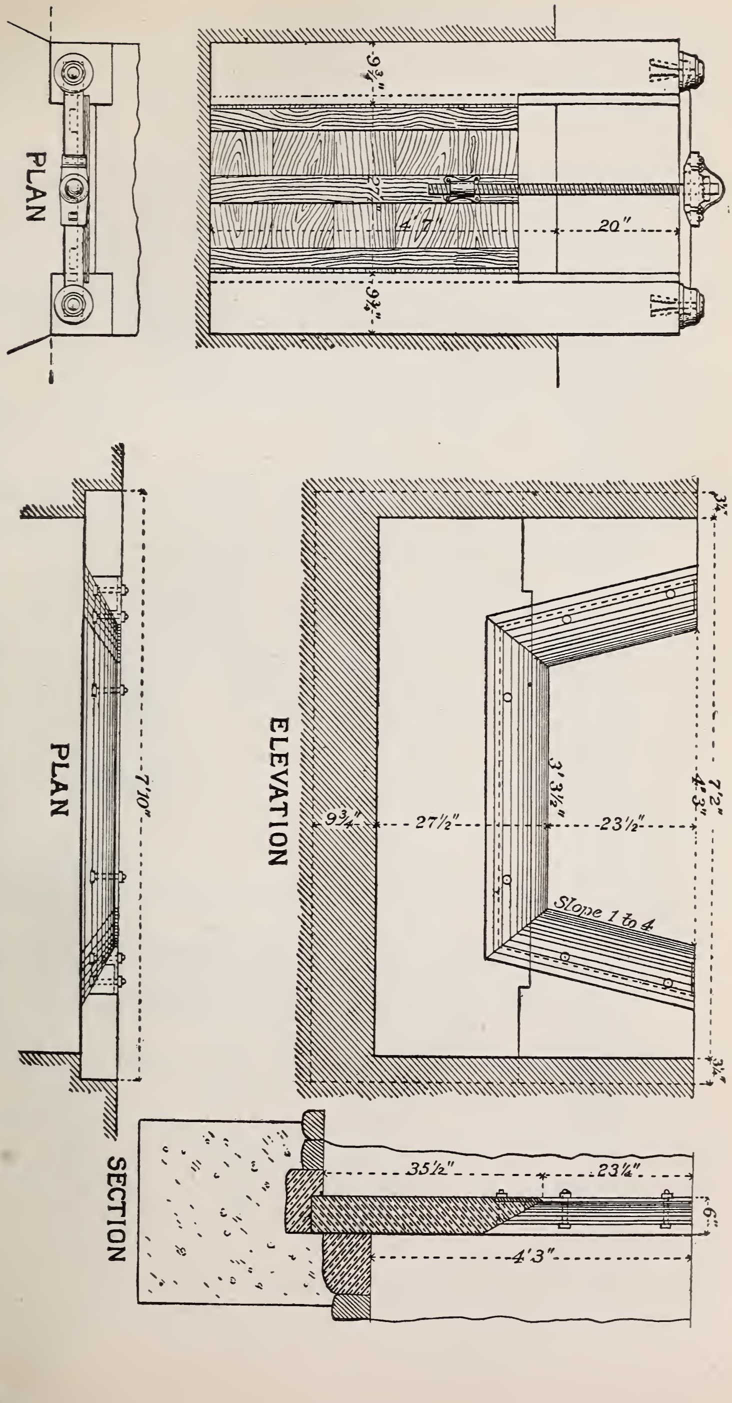


FIG. 6.—Details of head gate on lateral (on left) and measuring weir (on right), Villoresi Canal.

All the head gates, regulating gates, weirs, and lateral boxes on this canal are made according to standard types. The gates are all lifted by screws, the stems of which are covered by neat metal caps locked down by the water masters. Figure 6 shows the plan and elevation

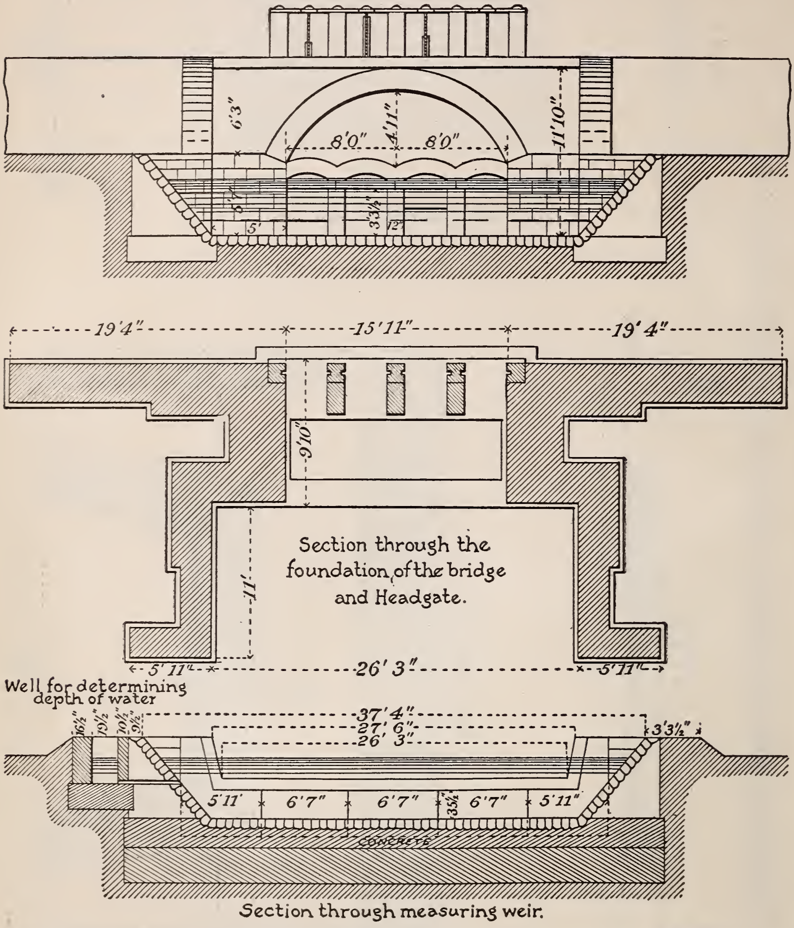


FIG. 7.—Vertical and horizontal sections of the regulating gates and vertical section of the measuring weir at the head of a branch canal.

of a standard gate at the head of a lateral and gives the details of a standard weir placed in the heads of laterals.

Figures 7 and 8 show the plan, vertical and cross section elevations, of one of the typical structures on a secondary canal.

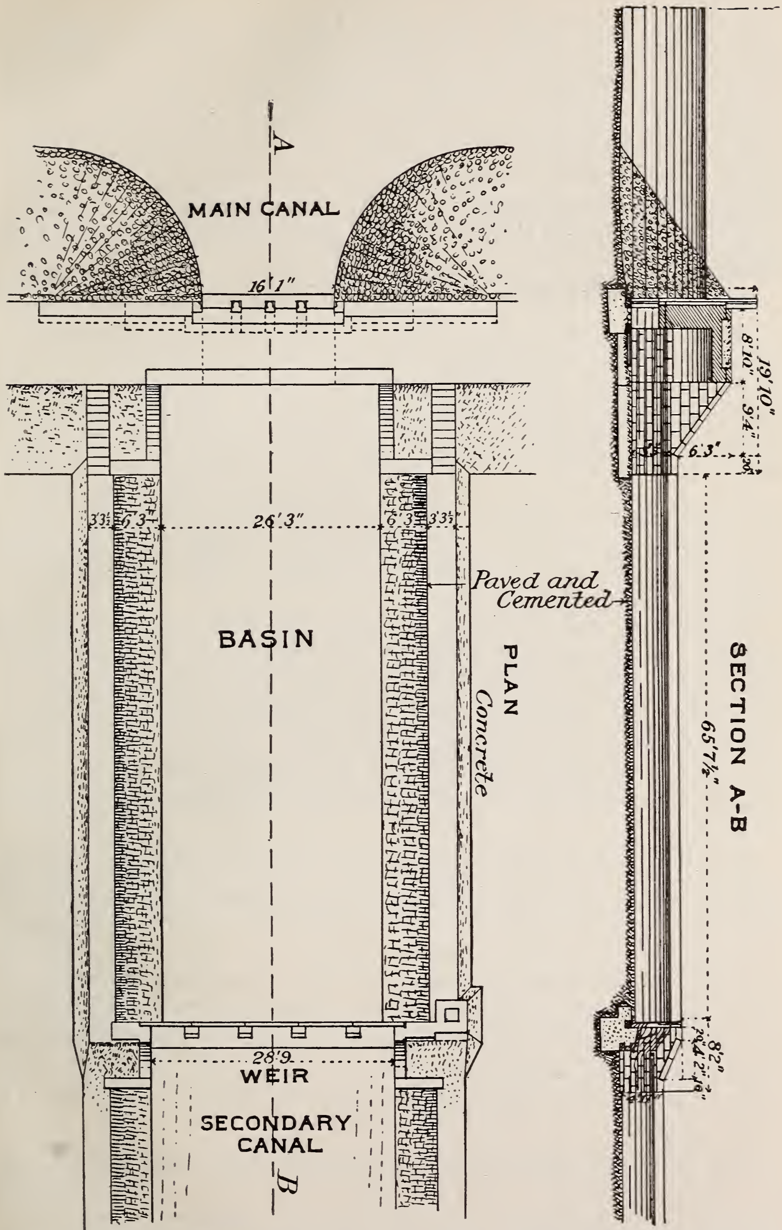


FIG. 8.—Ground plan and longitudinal section of regulating gates, basin, and measuring weir at the head of a secondary canal.

MANAGEMENT.

This canal is of special interest to American irrigators because it belongs to the same type as the largest irrigation works in the United States and its operation strongly resembles that of such canals as the Amity, High Line, and Del Norte in Colorado, the Wyoming Development Canal Company in Wyoming, the Bear River Canal in Utah, the Sunnyside Canal in Washington, and the Imperial Canal in California. The arrangements for delivering water have been worked out with more system than is shown in many similar enterprises in the United States.

The territory served by the canal is divided into four main districts, each of which is supplied by one or more branches. Several of these secondary canals are of large size, carrying over 300 cubic feet of water per second. The farmers who live under the branch canals are united into two classes of associations, one of which is a subdivision of the other. The field laterals that branch off from the secondary canals have as a rule each its own group of farmers united into a society called a "comizio." These together have representatives in the larger society which embraces the whole of the secondary canal or all of one of its more important branches. This larger society is called a "comprensorio."

The canal company does not as a rule retail water to the individual farmer. It sells it at wholesale to the comprensori, and these retail it to the comizi. The members of each comizio arrange for the division of the quantity of water they purchase among themselves. There are, however, exceptions to this rule. Some farmers refuse to go into the association, and to these the company sells water as individuals, the modification of the general plan being shown in paragraph 5 on page 45.

In selling water to these associations the canal company does not always charge the same price. Like a railway it charges for the distance the water is carried. The expense of delivering water at the lower end of the canal is greater than at the upper end. There is greater loss from seepage and evaporation, hence associations at the lower end are charged a higher price. Fortunately for these farmers the water they need costs them no more than farmers at the other end pay, because they can get along with a less amount. The soil in the eastern part of the district having more clay requires less water for its irrigation.

The cubic meter per second (35.31 cubic feet per second) is the unit of volume employed in the wholesale transactions. This is usually the basis of the contracts between the canal company and the comprensori. In the retail transactions the liter per second (0.035 cubic foot per second) is the unit employed. This is the usual unit where water is sold to comizi and is measured at the heads of their laterals.

Among the members of a comizio no attempt is made to measure the water. They make their division on a time basis, each one taking the full amount purchased for the number of hours per week, which represents his part of the payment. Thus, if 7 cubic feet of water per second is delivered at the head of a lateral, the farmer who pays for one-fourteenth of it would be allowed the whole amount for twelve hours each week.

The canal company does not allow farmers to sell water to one another. The right of use can not be shifted from the land described in the rental contracts without the consent of the canal company. A farmer is not allowed to irrigate one of his fields with water he has purchased for the irrigation of another.

It is not as easy for canal companies in Italy to be certain that regulations of this kind are observed as it is in America, because the farms are so much smaller. Many of the farmers under this canal do not cultivate more than 10 or 15 acres. The areas under the Villoresi vary from 2.5 to 740 acres, and the canal company's maps show the location and boundaries of each tract.

The canal company employs a large force of water masters to enforce these regulations. Each has about 6 miles of main canal and 12 miles of secondary canal to look after. From these secondary canals smaller canals lead to the field laterals. Each field lateral is designed to have 20 or 30 boxes on it to measure the supply to farmers. The work of the water masters and that of the farmers themselves in their various associations is under the direction of the canal company's division engineers. A day in August was spent with Antonio Bossi, who has charge of the most important division of the canal. He has been with the canal since its construction, twenty-two years, and has the supervision of 250 miles of secondary and branch lateral canals, which supply water to five of the seventeen comprensori or larger associations with which the canal company does business, the mileage under his direction in these different associations being as follows:

	Miles.
Magenta	83.7
Corbetta	86.8
Vittuone	23.6
Arluno	34.1
Bareggio	12.4

WATER-RIGHT CONTRACTS.

Irrigators under the Villoresi Canal can obtain water in one of three ways:

(1) Water is furnished at 30 lire per liter per second ($166 per cubic foot per second) as an annual rental, with 5 lire ($1) additional annual payment on the purchase price of a perpetual water right in the canal.

These annual payments of 5 lire are to continue for forty years, making the cost of a perpetual water right to 1 liter per second, $40.

(2) Water is furnished at 30 to 40 lire for one hour's run each week of 200 liters per second ($5.80 to $7.75 for one hour's run each week, of 7 cubic feet per second).

(3) The canal company sells water to farmers' associations at wholesale under special agreements, placing the expenses and supervision of delivery on the associations.

The canal company each year publishes large posters giving the terms under which it will furnish water. The following is copied from one of these notices, and is substantially the basis followed from 1898 to 1903, inclusive, in supplying water to irrigators under the third plan outlined above:

Italian Society for Aqueducts (Villoresi Canal).

MILAN BRANCH. MAIN OFFICE AT ROME.

(Notice to the associations of Turbigo, Robecchetto, Castano, Cuggiono, Magenta, Corbetta, Vittuone, Arluno, Bareggio, Valle Olona, Rho.)

The society (Villoresi Canal Company) notifies the members of the organized associations that during the summer season of the year 1902 water will be furnished according to the following rules:

(1) From April 15 to September 10, 200 liters of water may be used during a period of one hour each week, 35 lire.

(2) From June 30 to September 10, 200 liters of water may be used during a period of one hour each week, 30 lire.

Applications for water under the conditions of paragraph 1 must be made not later than April 10, and applications for water under the conditions of paragraph 2, not later than May 3. No applications for water under either class will be granted after these dates, respectively.

The society reserves to itself the right of limiting the use of water under both class 1 and class 2 to August 20, without reduction of price.

(3) In addition to the prices provided for in classes 1 and 2, the users shall pay 5 lire for every hour during which they receive water, to meet the expenses of operating and maintaining the secondary canals.

(4) The first irrigation period shall occur within eight days after the above-mentioned date for the beginning of the irrigation turn, pursuant to an agreement with the board of directors, but the irrigation period may be changed subsequently, if necessary.

(5) The delivery and measurement of the water for all the applicants belonging to each district shall be made altogether at the modules at the heads of the distributing ditches, either in the secondary or in the main canal, and the water shall be distributed by the superintendents and water masters of the associations, without any responsibility on the part of the company for such distribution.

(6) If the aggregate of the irrigation periods requested for any one weir (see paragraph 5) exceeds one hundred and sixty-eight hours, the society may increase the amount of water to be distributed and proportionately decrease the length of the irrigation periods, without liability for damages or compensation.

(7) Applications must be made at the office of the society in Milan via Paleocapa No. 4, on holidays from 9 a. m. to 12 m., and on other days from 9 a. m. to 12 m., and from 2 to 5 p. m., or to the assistants. And payments are to be made at the time applications are filed.

(8) If for any reason whatever it is impossible to grant application, either wholly or in part, for water to be delivered over a weir (see paragraph 5), the applicant shall be reimbursed only in a sum proportional to the deficiency in the amount of water supplied and to the period during which such deficiency continues, without recourse for any damages whatever.

(9) Applications made by those who are not the owners of the land to be irrigated will not be granted unless accompanied by written authorizations from the owners.

MILAN, *March 1, 1902.*

The Vice-Director,
ING. GIOVANNI SCHIAVONI.

Some of the associations have special agreements under which they receive water on a plan different from that shown by the above notice. The association of Corbetta pays 45,000 lire ($8,785) per year and receives 1.8 cubic meters (63.6 cubic feet) of water per second from April 2 to September 21, and an additional 2.2 cubic meters (77.7 cubic feet) of water per second from June 20 to August 25. This is an average of 93.7 cubic feet per second for the entire season from April 2 to September 21, at $93.75 per cubic foot per second for the season. This contract between the association and the canal company is for a term of six years, these long-term contracts being one of the interesting features of water-right agreements in Italy. The conditions of this contract are as follows:

(3) The water acquired by these users will be measured and delivered partly at the measuring weir at the head of the secondary canal at Corbetta and partly at the measuring weir of the second district that is supplied from the basin of the above-mentioned secondary canal; partly at the measuring weirs of the first and second districts, which receive water directly from the main canal. The water will be measured and delivered according to the quantities and schedules communicated by the officers of the association to the Italian Society. The distribution of water at the measuring boxes of the districts along the Corbetta Canal shall be made by the association at its own expense, as well as the distribution in the canals of the association below the modules. The Italian Society will, however, clean, maintain, and repair the secondary canal and all the modules for measuring water to the same secondary canal and to the districts.

(4) The above-mentioned water will be distributed to the districts of the Association of Corbetta by the officers of the association and will be distributed if possible in a rotation running through seven days and in a quantity of 200 to 320 water liters (7 to 11 cubic feet per second) according to the judgment of the supervising committee of the association, taking into consideration the kind of land to be watered, the distance from the measuring box, and the kind of distributing ditches and laterals. Each subscriber will have the right to use a stream for fourteen minutes for every pertica of meadow and four minutes for every pertica of other crops.

(5) The water for the lands of those not members of the association will be at the disposal of the Italian Society, or its representative, and will have the following water hours for each period (see No. 2): To each of the districts[a] 1, 2, 3, and 4,

[a] An official map is made of the irrigated territory included in each association and the districts in this territory are numbered. The numbers given in paragraph 3 refer to the districts as numbered on this official map. The land of nonmembers is interspersed with that of members and is watered from the same laterals, but under separate agreements.

five hours; to each of the districts 5, 6, 7, 8, and 9, seven hours; and for each of the districts 10, 11, 12, 13, 15, and 21, nine hours. The society has the right to change a part of the water from one district to another, but not in such a manner as to give more than twelve hours to nonmembers in any district. That part of the period of rotation which has not been assigned to those who are not members of the association will be at the free disposal of the association. The parochial prebenda and ecclesiastical beneficiaries that have made special arrangements with the Italian Society in order to have the same rights as the members (of the association) are considered in this case as being members. If any parties who are not yet in the list of members desire to enter that list before the month of June, 1903, with the purpose of receiving the water under the conditions of this agreement, the officers of the association will have the right to give them water so long as this agreement continues. The money paid by these parties for water will be divided equally between the society and the subscribers to this agreement. In this case the society renounces a part of the hours it has the right to have under article 3 in the districts belonging to the parties that have become parties to this agreement.

(6) During the six years (paragraph 1) the undersigned consumers must use the water purchased only on the lands belonging to themselves, as located on the maps of the association or for lands represented by the undersigned consumers in this agreement, and located on the maps of the association. In case of violation of this rule the society has the right and the association has both the right and the duty of cutting off the water of the consumers who violate the rules. For this stoppage of water the consumer has no right to ask damage; on the contrary, the rights of the society are unimpaired and the consumer is obliged to pay the price fixed in paragraph 5.

(7) For the water put at the disposal of the undersigned consumers these consumers obligate themselves and their successors to pay to the Italian Society in Milan, in two installments, one on the 15th of June and the other on the 15th of July of every year during the present agreement, 45,000 lire, divided among the subscribers according to the schedule in paragraph 14. In said sum of 45,000 lire, and in the sums to be paid by every subscriber, is included the annual rental for partnership water and the annual payments for the sinking fund to the Italian Society for Aqueducts. The receipts of the society (Villoresi Canal Company) to its customers shall show that they have paid the annual sinking fund. If a consumer has not paid within fifteen days after the time fixed, the society has the right and the association has the right and duty of cutting off the use of water to that consumer under the conditions stated in paragraph 5. In any event, this consumer has to pay the society interest at the rate of 5 per cent per annum for the amounts that he did not pay at the proper time, for the period from the date when due to the date of payment, deducting the fifteen days' grace granted as above.

(8) It is agreed that each consumer shall obligate himself individually and his successors to the Italian Society for the amount that he is to pay according to paragraph 15.

(9) All the subscribers to the present agreement obligate themselves to take water for all the land shown on the map of the association, both meadow and cultivated land. In the fourteenth, fifteenth, and twenty-first districts, the lands which the members of the association will not water from the Villoresi Canal during the six years of this agreement shall not be considered if the supervising committee of the Corbetta Association will admit that they are provided with their own water supply. One or more members will be permitted to represent the water belonging to members not signing the agreement, assuming all the rights and duties toward the Italian Society. Payments for water shall be based upon one pertica of the land shown on the map of the association, and at uniform rates for the different kinds of land in the different zones of the association. For list of the sums to be paid by each

subscriber see article 14. In these sums are included what is to be paid by the subscribers for partnership water. The payments to the sinking fund of 5 lire for 1 liter are to be added to the sum which each subscriber is to pay to the society. For no reason can a subscriber pay less than the price of the water for which he originally subscribed. In case the amount raised by the above-specified uniform rates and the sums for the sinking fund do not reach a total of 45,000 lire, the subscribers obligate themselves, if it is necessary in order to reach that sum, to increase the amount they have to pay 5 per cent, excluding their payments to the sinking fund.

(10) If any members, directly or through their tenants, have already assumed obligations for water from the association, or for the rental of water advantageous to the Italian Society, it is agreed that if said members, or their tenants, do not accept the present agreement, those who sign will consent that the association place at the disposal of the members not consenting, or their tenants, the water for which they have contracted, and the Italian Society for Aqueducts will include in the 45,000 lire agreed upon the payments to be made by these members, and will be responsible for their collection.

(11) If for any reason the water supply is partially or entirely deficient (articles 1 and 15) the Italian Society shall refund to the undersigned customers a part of the sums paid in, proportional to deficiency and its duration; but no account shall be taken of a deficiency in the water supply during the spring time prior to April 15. Equal reimbursements shall be made to subscribers in districts in which irrigation is forbidden by order of the public authorities. No money shall be refunded by the said Italian Society under the last-named condition, provided the suspension or prohibition takes effect after August 15.

Reimbursements shall be made at the office of the Italian Society in Milan on the 30th of September of each year in which there is a deficiency in the water supply or in which irrigation is prohibited; but it is stipulated that such deficiency or prohibition shall not in any way remove the obligation of paying to the Italian Society the sums fixed and at the time specified, as provided by article 6.

(12) If the association finds it necessary because of heavy rains or other reasons to reduce the amount of water supplied (see articles 1 and 2), the Italian Society for Aqueducts guarantees to arrange for the required reduction within a period of forty-eight hours.

(13) This agreement must be subscribed to on or before February 10, 1898. If at that date the amount subscribed has not reached the sum of 45,000 lire, including the assessment of 5 per cent provided for in article 9 (last clauses), this agreement shall be void and without effect.

(14) The expense of preparing this agreement, which shall be written in duplicate, one copy to be kept by the Italian Society and the other by the association, and the tax to be paid to the Government, etc., shall be paid by the consumers signing hereto in proportion to the shares or sums set opposite their names. In order to determine the correct amount of tax due, we declare that in this sum of 45,000 lire (see article 6) are included 9,089.50 ($1,817.90) for 259.7 liters of partnership water at 35 lire ($7) per liter already purchased by the subscribers to this agreement, in accordance with previous agreements, the taxes arising from which have been duly paid, in consequence whereof the amount on which the tax is to be levied is to be reduced to 35,910.50 lire annually for six years, or a total of 215,463 lire ($43,092.60).

For the summer season of 1903 the canal company sold the association at Magenta 176.6 cubic feet of water per second for $12,353, or $70 for a cubic foot per second, as against $93 per cubic foot per second paid by the Corbetta Association. The water was measured

where the Magenta branch left the secondary canal, and the association had to stand all the losses from seepage in the laterals. This varies in different laterals from 15 to 50 per cent, the average being about 30 per cent, making the cost of the water actually used by irrigators around Magenta $100 a season for each cubic foot per second.

SEEPAGE AND DRAINAGE UNDER THE VILLORESI CANAL.

There was abundant evidence of heavy seepage losses from laterals. A gravel pit near a cemented lateral was filled with water within 7 feet of the surface of the surrounding ground. Soon after irrigation began in the Corbetta district seepage water filled the subsoil, flooded the cellars of the town of Vittuone, and made it necessary for the municipal authorities to build drains for their relief. The town dug an intercepting ditch across the higher land back of it, and an outlet ditch from this, coming out on the surface below the town. The intercepting drain caught several cubic feet per second of the seepage water, which the city authorities sold to the irrigators below the town, making the work pay a handsome revenue.

In several other sections under this canal the soil water had flooded the cellars of residences and dairies, turned the fields into bogs, spoiled crops, and killed the mulberry trees. These evils became so general that a law was passed requiring the canal company to either drain the land or close its ditches. Since neither the canal company nor the farmers wanted the ditches closed, an agreement was made under which they are to share the expense of drainage, the canal company paying 40 per cent and the farmers 60 per cent. These drainage works are being planned and built on the same solid and comprehensive scale as the irrigation canals and laterals.

The drainage agreement between the company and the Corbetta Association provides for the construction of a drainage canal to carry 106 cubic feet of water per second, and a number of other drains ranging in capacity from 17 to 70 cubic feet per second. A copy of this agreement is given below.

Whereas, according to the provisions of paragraph 112 of the regulations of the Corbetta Association, the Italian Society for Aqueducts is under obligations to build a drainage canal for removing running water, with a capacity of not less than 3 cubic meters per second (105.93 cubic feet); and

Whereas in the assembly of April 29, 1894, the members of the association decided to build the above-mentioned canal; and

Whereas, by the decrees of the prefect of Milan, dated August 3 and October 11, 1898, the irrigation of certain lands belonging to the Corbetta Association has been prohibited until necessary drainage canals shall have been constructed; and

Whereas, despite the appeal of the association, the minister of public works not only ratified the above-mentioned decrees by his decree of August 9, 1899, but also announced that the prohibition might be extended to a larger section; and

Whereas the purpose of two canals—one for the discharge of running water, and the other for the discharge of drainage water—could be met by the construction of a single canal having in view this double object;

Therefore this agreement has been arranged between the Italian Society, represented by Engineer Giovanni Schiavoni, and the Corbetta Association, represented by its president—Mr. Roberto Battaglia.

AGREEMENT.

Article 1. The Corbetta Association—

(a) Shall extend the Corbetta secondary canal from its present termination at the northwest corner of land No. 989, of Corbetta, owned by Mussi Dott. Giuseppe, to the Naviglio Grande, according to the plan indicated by the heavy red line in the diagram and in the profile attached hereto and made a part of this agreement.

(b) Shall build two branches of the drainage canal to remove seepage waters from the Pobbietta, Pobbia, and Malpaga dairies and adjacent lands, according to the plan indicated by the light red line in the diagram and in the profile attached hereto, as above described.

(c) Shall enlarge and so arrange the Corbetta secondary canal from the lateral at the southeast corner of No. 227 of the Corbetta map, owned by Isimbardi March Luigi, to the above-named northwest corner of No. 989 of the same map, that the said enlarged secondary canal shall have a capacity of 2 cubic meters (70 cubic feet) per second.

Article 2. The new part of the secondary canal shall be made with such slope and section as to have a capacity of 2 cubic meters per second, and its bed shall be at low enough level to receive seepage from higher lands and from buildings through other drainage canals and ditches (see paragraph 4), and do no damage by its own seepage.

The parts of the two branches of the drainage canal that are to run along the Pobbietta, Pobbia, and Malpaga dairies must have their beds 4.92 feet below the lowest points of the said dairies and must have a slope of not less than 42.24 feet per mile to reach the present secondary or the new canal at the points marked B and C, respectively, on the diagram referred to in article 1, so that the level of the water in the branches at the points indicated shall never be lower than the highest level of water in the present secondary canal or its extension, thus permitting the waters to always flow freely without backing up.

Article 3. The canals described in article 1 must be completed within eighteen months from the day in which authority is given to discharge the said 70 cubic feet into the Naviglio Grande and the date of the decree declaring the work of public utility.

Article 4. The association shall always be permitted to extend the said drainage canals, to unite them to others, build separate special sections of them whenever seepage waters or damages are manifest in other places, and to discharge these waters also into the secondary canal or its extension at the points named in article 2 or at other points.

Article 5. The actual surveys for the canals (see article 1) shall be made under an agreement between the society and the association, and the parties will try to keep the expenses for surveys, for contracts with parties interested, for active and passive servitudes (including those for discharging or in any other way removing the surplus waters during the time the Naviglio is closed, which discharges, depending upon the season when the closing occurs, may be estimated at 17.65 cubic feet per second), for excavation, for construction work, etc., within $22,000.

Article 6. The regulations of the association governing the obtaining of rights of way for lateral and distributing canals shall apply to the obtaining of lands, their occupation during construction, and the compensation to members, for the canals described in this agreement.

Article 7. The society (for aqueducts) may dispose of the water collected in the canals provided for in articles 1 and 4 as it does of the water from the main Villoresi

Canal. For this purpose it may open and maintain at its own care and expense, along the line of the secondary canal, the necessary gates in accordance with the provisions of article 2.

Should the association desire to use, for the purpose of distributing the water belonging to the members of the twenty-second district, that part of the secondary canal that extends from the northwest corner of No. 989 of the Corbetta map, the property of Mussi (see article 1) to the northwest corner of No. 1014a of the said Corbetta map, the property of Zanzoterra, formerly belonging to Bruni, instead of the lateral now used—it may open and maintain at its own risk and expense the necessary gates along the new part of the secondary canal.

Article 8. As the drainage canals of the Pobbietta, Pobbia, and Malpaga dairies and adjacent lands described in articles 1 and 4 would discharge their waters into the secondary canal, and as these drainage waters would mix with those of the Villoresi Canal and might perchance be purchased by the users, the users of water already sold and the association for them renounce any claims in the premises.

As for the water that may hereafter be purchased, the Italian Society for Aqueducts, for itself and for those subordinate to it, agrees to add in the contracts for the sale of water of the Corbetta Association a special paragraph covering this renunciation in accordance with a plan already agreed upon by the commission of the association.

Article 9. The Corbetta Association shall have the right to request and the Italian Society shall be under obligations to grant a sufficient decrease in the amount of water running in the Corbetta secondary canal, so that it shall carry not more than 35.31 cubic feet per second in the case of heavy rains, overflow, breaking of canals, and similar accidents.

This request on the part of the association must be in writing, through the board of directors or the manager, and delivered to the Milan office of the Italian Society at least thirty-six hours before the time when the decrease in the amount of water is desired. This application must clearly set forth:

(a) The day and hour when the amount of water in the secondary canal is to be decreased.

(b) The amount of water to be cut off from the said canal. So long as the canals provided for in article 1 are not constructed and ready for use, the Society must close the secondary canal at its head in the main canal at such time and to such extent as may be requested, in accordance with the last part of paragraph 112 of the regulations of the association.

Article 10. The Corbetta Association relieves the Italian Society for Aqueducts and the first association for the North Lombardy Canal of all liability for claims which members of the Association may make because of the diminution in the amount of water in the secondary canal of the Corbetta Association made as provided for in article 9. The Italian Society, on its part, in all contracts for rent or sale of water, either for irrigation or power, to the Corbetta Association, shall add a clause whereby it shall have authority to make the above-described diminution in the amount of water flowing in the secondary canal, and the purchaser or renter of water shall make no claim for damages or compensation. The insertion of such clause is hereby agreed to by the commission of the association.

Article 11. As the enlarged and extended secondary canal will have a capacity of 70 cubic feet per second, as provided for in articles 1 and 2, it is hereby agreed that the said secondary canal shall always be absolutely at the disposal of the association to receive the drainage waters up to a capacity of at least 35.31 cubic feet, and at the disposal of the Italian Society to receive drainage waters to the extent of its remaining capacity. But in any event the association shall always have the right to enlarge the secondary canal and extend the same, as provided for in article 4, when the drainage waters shall exceed a discharge of 35.31 cubic feet per second.

ARTICLE 12. The cost of the canals provided for in article 1 shall be paid in the following proportion: Sixty per cent by the association, to be apportioned according to the area, and 40 per cent by the Italian Society for Aqueducts. The extension of the secondary canal shall be maintained according to the rules set forth in the regulations of the association. The drainage canals provided for in articles 1 and 4 shall be maintained at the expense of the association and such expense shall be apportioned according to the area.

ARTICLE 13. This agreement shall take effect and become binding upon the association and the Italian Society whenever the Government shall have granted permission to discharge the 70 cubic feet of water per second, described in article 11, into the Naviglio Grande.

When this agreement goes into effect the obligation on the part of the Italian Society for the construction of a drainage canal ceases. This obligation was imposed by article 112 (temporary regulations) of the regulations of the association, attached to the agreement, acknowledged by the Notary Bertole, Nos. 1044–5025, on November 23, 1884, and filed in Milan December 11, 1884, No. 4075, vol. 297, page 160, private agreements.

ARTICLE 14. This agreement shall go into effect whenever ratified by the Italian Society, represented by its board of directors, and by the Corbetta Association, represented by the assembly of members.

The canal company has a right to the water collected by the drains and where possible turns the drainage water back into its canals.

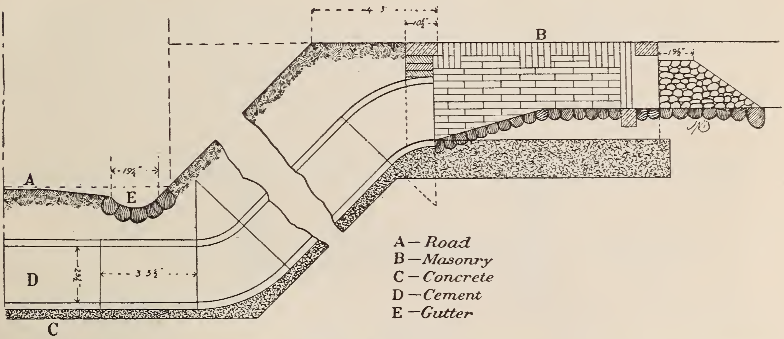


FIG. 9.—Masonry and concrete siphon carrying the water of a lateral under a road—standard plan.

Plate VII, figure 2, shows where a drain empties into a ditch just below a drop, (*a*) being the lateral and (*b*) the drain ditch. This drain was discharging 7 cubic feet per second at the time, this water being worth $656 a year at the rates paid for water by the Corbetta Association. Farther down drains empty into the Naviglio Grande, the right to use it for seepage water having been granted by the Government.

The numerous public and private roads add greatly to the cost of both irrigation and drainage ditches. State and local regulations require that both bridges and siphons shall be of iron or masonry and shall prevent water injuring the roadways. Figures 9, 10, and 11 show the details of some of these structures.

The damages from seepage and the expense necessary for drainage have led to efforts to check losses from canals by lining them. The

engineers of the Villoresi Canal have found the cement lining unsatisfactory in many ways, especially for laterals. These are frequently empty and at such times the intense heat of the sun causes unequal expansion which cracks the coating, especially on the sides. Engineer

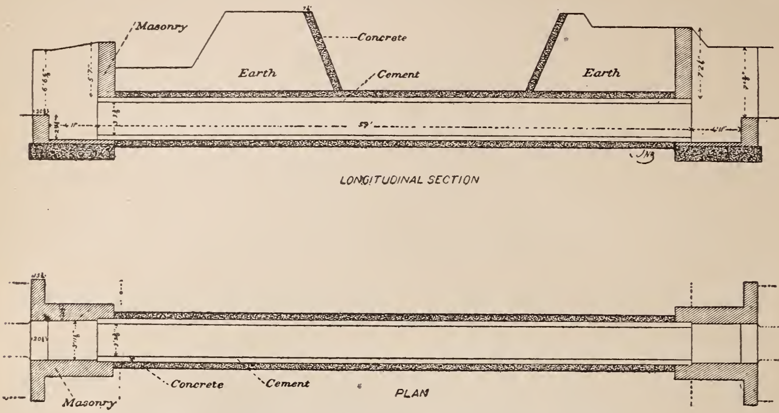


FIG. 10.—Siphon carrying water of a lateral under a canal.

Bossi said that his twenty-two years' experience had caused him to believe that it did not pay to pave and cement the sides, and that hereafter he would cement only the bottoms of laterals. There he would put the concrete floor 10 or 12 inches below grade and cover it with

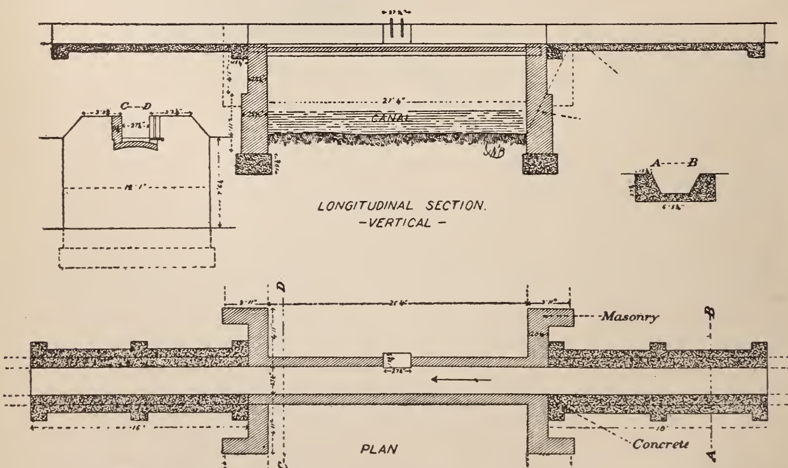


FIG. 11.—Iron, masonry, and concrete crossing of a lateral over a canal.

this depth of earth, so as to prevent damage from both frost and heat. He was also experimenting with other materials, coal tar mixed with sand being the one looked on with the most favor.

For the past three years the irrigation investigation of the Office of Experiment Stations has been experimenting with linings for canals to find something less costly than cement. In many parts of the West cement is not a satisfactory material. Frosts in winter lift and crack it and the hot sun of summer helps to hasten its destruction. Puddled clay, a mixture of earth and crude oil, paper, and asphaltum are some of the substitutes for cement tried or considered.

RIGHTS OF WAY.

The Villoresi Canal, with its network of laterals, has to pass through a densely populated, highly improved country, where lands are high-priced and farms as a rule small. The cutting of a canal 30 feet wide through a farmer's yard, or the taking of the land it required out of a 5-acre farm, was not apt to be looked upon with favor by the farmers, and if the canal company had been compelled to litigate questions of damages for right of way, as ditch companies do in some Western States, the canal would never have been built. The company avoided this by having the farmers' associations secure the rights of way for both irrigation and drainage works. In doing this the association at Corbetta systematized the determination of damages by arranging a schedule of values for different improvements. After it had secured the adoption of this schedule by the farmers it was made the basis of the following contract between the association and the canal company:

Agreement between the Villoresi Canal Company and the Corbetta Association for the settlement of rights of way for the passage of water in accordance with the regulations of the Association.

(1) The said ——— (individual or corporation), living in ———, grants servitude for the passage of the waters of the ——— Canal through the hereinafter-described lands (see No. 15) to the association.

(2) The uniform price for the land on which the servitude shall be established for the bed of the ——— Canal, for the deposit of cleanings, for the side embankments, etc., is fixed at 6 cents per square meter (0.56 cent per square foot) of surface to be occupied for the above-mentioned purposes. This price does not include the indemnity either for growing fruit or for the mulberry trees, which shall be established as follows:

Growing fruit shall be paid for at the uniform rate of 2 to 3 centimes per square meter (0.04 cent to 0.06 cent per square foot).

Mulberry trees shall be valued according to the following scheme:

Trees of very small diameter	\$0.32
With diameters up to 1.968 inches	.40
With diameters from 1.968 to 3.937 inches	.60
With diameters from 3.937 to 5.906 inches	1.00
With diameters from 5.906 to 7.874 inches	1.80
With diameters from 7.874 to 9.842 inches	2.40
With diameters from 9.842 inches to 1.083 feet	3.20
With diameters from 1.083 to 1.312 feet	3.60

If the notice of the destruction of trees (in accordance with paragraph 8) shall be given after the month of April, compensation for the first four sizes of mulberry trees shall be as follows:

Trees of very small diameters	$0.50
With diameters up to 1.968 inches	.60
With diameters from 1.968 to 3.937 inches	.80
With diameters from 3.937 to 5.906 inches	1.20

but the prices for the other sizes shall be the same.

The above-named prices for mulberry trees are for those of vigorous growth; suitable reduction shall be made for trees of poor growth, based upon the advice of the expert sent out by the association, and for those in hedges or wind-breaks the price shall be reduced one-third.

The land necessary for borrow pits shall be valued at four-fifths the above-quoted price per square meter. These borrow pits shall not be more than 6.56 feet below the level of the country, and shall be made in regular geometrical shape, with slopes of 1 to 1.

The land occupied by refuse materials shall be valued at one-half the price paid for that occupied by permanent works.

Upon the advice of the expert the proprietors will be permitted to take from the borrow pits a stratum of earth not more than 7.874 inches deep, before turning them over to the association.

The temporary occupation of land by construction materials shall be paid for at the rate of 0.06 cent per square foot for uncultivated land and 0.09 cent for cultivated land.

The land segregated shall be valued according to the following rules:

(a) If parallel to a private, partnership, or community road, and if on the strip taken there is a row of mulberry trees and hedges of acacia, 0.18 cent per square foot.

(b) If there is only a row of mulberry trees, 0.24 cent.

(c) If there is only an acacia hedge (if the strip to be kept is less than 3.28 feet wide on the average) 0.11 cent per square foot.

(d) When the strip to be kept is on the edge of an estate, if there is a row of mulberry trees and acacia hedges, 0.22 cent per square foot.

(e) If there is only a row of mulberry trees, 0.27 cent.

For rights of way within the estates of others in addition to the compensations provided for above, the right of passage along a small path beside the canal shall be provided for.

(3) The proprietor shall not be entitled to the compensation provided for in the preceding paragraphs for trees that, after the construction of the canal, are found to be more than 2 feet from the side of the canal, in accordance with paragraph 69 of the regulations.

(4) In the uniform price of the land (see paragraph 2) is included, in addition to the value of the land on which the servitude shall be established, all compensation due the landowner who has granted that right, for the capital upon which the agricultural tax, payable by the member, is based, and compensation for all damages arising from the construction of the canal, including damages incurred during the making of surveys and plans. Therefore the party who has granted the servitude may not ask any further compensation for any reason whatever in addition to the above-named price. This price does not include any damages that may be incurred through accident on the right of way, either during the surveys or during construction.

(5) The association shall be permitted to take possession of the property on which the servitude is established and to carry on the work of construction five days after giving written notice to the party granting the right.

(6) Before commencing the work of constructing the canal, the crops will be appraised and the mulberry trees to be removed shall be counted. A copy of the findings shall be given to the owner for verification and final settlement.

(7) If during construction of the canal, it shall become necessary to remove any other tree in addition to those enumerated, previous notice shall be given the local representatives of the owner and the superintendent of the work shall make a statement in writing of the kind and size of trees removed.

(8) The trees on the lands to be occupied by the canal and accessory works remain the property of the party granting the right of way, but he must have them cut down and removed within eight days after notice is given by the association.

(9) Interest at the rate of 5 per cent shall be paid on the amount of compensation for land, trees, and growing fruit provided for in the settlement (see paragraph 14) from the ——— day of ——— until payment is made to the owner, according to paragraphs 68 and 70 of the regulations.

(10) The rights of way for dumping material cleaned out of canals, according to paragraph 2, shall be 1.64 feet wide. These, beyond the deposit of excavated materials, shall be used as passageways in repairing and guarding the canal; consequently, the owner must keep them free from cultivation or any other obstacle with the exception of grass, which shall be the property of the owner.

(11) The proprietor shall not be permitted to plant new crops or to increase those existing along the canal, within a distance of 3.28 feet from the side of the canal if built in excavation, and from the foot of the exterior slope if built in embankments in accordance with paragraph 69 of the regulations.

(12) The party granting the servitude shall not have the right to turn water into the canal of the association and must renounce every privilege granted by the law in this regard.

(13) The owner shall be responsible for all claims of tenants, users, and all persons who can advance any claim against this occupation.

(14) When the canal and accessory works shall have been completed, determination of the actual amount of land occupied shall be made by the expert delegate. Final settlement shall be based upon this determination and the amount of principal and interest, as provided for in paragraph 9, shall be credited to the owner.

(15) The land subjected to servitude in accordance with this agreement is described on the map of the above-named community of ——— under part of the Nos. ———.

The cost of the main and secondary canals of the Villoresi was about $3,000,000. The exact cost of the laterals, the measuring boxes, and the drainage works could not be ascertained, but it was the opinion of Engineer Bossi, whose long connection with the canal has given him unusual opportunities for knowing, that the entire outlay for the system has been not less than $6,000,000, or $37.50 an acre for all the land which the canal can reach. The whole of this outlay is not, however, to be charged to irrigation. The power ditches cost a large sum and the rentals of water for power purposes are important additions to the company's income. As an irrigation enterprise, it affects the well-being of the 150,000 people, and over 8,000 farmers rent water for irrigation.

AGRICULTURE UNDER THE VILLORESI CANAL.

There is so little difference in the country watered by the Villoresi Canal that the area irrigated by the Corbetta Association may be taken as fairly typical. Certainly it is a fair average. More water

is used here than in the country farther east where the soil contains more clay, and probably less water than along the borders of the Ticino where the land is more gravelly. The land irrigated by the Corbetta Association is subdivided into twenty-two districts. Each has an area of about 740 acres with its own delivering weir and main lateral. From these main laterals many smaller ditches reach out into the farmers' fields.

The conditions under which farmers work in this part of Italy are wholly different from those which prevail in the arid region of America. In the midst of the Corbetta district there are farms which are being cultivated without irrigation which grow the same crops as surrounding farms that are artificially watered. Farming by rainfall alone here is not unlike farming in Kentucky, Tennessee, southern Missouri, and northern Arkansas. The rainfall in Italy is, if anything, a little greater and is equally well distributed.

In the fields devoted to wheat only one crop a year is grown where irrigation is not practiced, but where the land is irrigated a good crop of corn, beans, or cabbage can be planted and brought to maturity after the wheat is harvested. Without irrigation clover and alfalfa, if sown with wheat, make a small growth, but with irrigation a good crop can be cut the same year after the wheat is harvested and the stand in succeeding years is better because of the vigorous growth while the plants were young, due to irrigation. The following are notes of talks with farmers:

One farmer pays a rental of $7.32 for 7.15 cubic feet of water per second from 7 to 8 o'clock each Monday morning from April 7 to September 18. This was not quite sufficient to irrigate his field in 1903 and he purchased an additional 7.15 cubic feet of water per second for fifteen minutes each Monday morning. This extra irrigation service continued only during the hottest part of the season, from June 30 to September 8. For this extra fifteen minutes he paid $1.70. This shower, lasting an hour and a quarter each Monday morning, cost him for the season $9.02, which was about $1.20 an acre.

Another farmer bought seepage water to irrigate his land. He paid only about one-half the regular price charged for water by the canal company, making his water rental about 60 cents an acre. This tenant said that his most profitable crop is mulberry leaves, which he feeds to silk worms. Silk raising is an important feature of agriculture in the Corbetta district, nearly every field having some mulberry trees. These are, however, a special crop and do not affect the general rotation of crops. As silk raising is not well understood in the United States, some description of the methods of carrying it on in Italy may be of interest.

The eggs from which the cocoons are hatched are raised by men who make this business a specialty and who keep the eggs under proper

conditions to maintain their vitality until time for the farmers to purchase them in the spring. The quantity of eggs purchased by each farmer is determined by his probable crop of mulberry leaves, and they are by practice able to gauge the number of worms which can be fed. For the eggs the farmer pays $2.40 to $3 an ounce. An ounce of eggs will produce on an average 110 pounds of cocoons which the farmer sells at about 35 cents a pound. The expenses include the purchase of eggs, the coal and wood for the warming room while the eggs are hatching, the gathering of the leaves, and the feeding of the worms while they are growing.

Irrigation increases the crop of mulberry leaves about one-third and makes the rate of growth more uniform than where rainfall is the sole dependence. Several farmers said that if water for irrigation cost less, hay and mulberry leaves would be the most profitable crops, but as the water required to irrigate 8 acres of hay will irrigate 20 acres of corn, wheat, or clover, the lessened outlay for water makes them favor diversified farming.

The irrigated land in this section sells for 50 to 100 per cent more than the unirrigated. Land which formerly sold for $80 an acre now brings $160. Unirrigated land under the Parabiago Canal now sells for $100 an acre, and the price where irrigated ranges from $160 to $200 an acre.

The canal has now been completed twenty years, yet in 1903 many fields were being prepared for the first application of water. A better understanding of conditions makes it clear why irrigation has been extended slowly. The expense of preparing the land for irrigation is far greater than men not familiar with the subject suppose, and far greater than well-informed persons realize until they have had some actual experience. The building of laterals or the payment of water rentals are not the most important outlays. There must be intensive cultivation, more laborers must be employed, larger barns to hold the crops and more houses to shelter the workers must be built. It is these expenditures that have delayed the complete irrigation of lands under the Villoresi Canal.

Where land is rented, the tenants pay one-half the water rental and give one-half the crop to the owner, or if the landowner pays the water rental he receives more than half the crop.

The farmers talked with were courteous and intelligent. Their conversation was marked by originality and independence. Their homes, clothes, and food gave no evidence of squalid poverty. On the contrary, many of the homes were more attractive and comfortable than those of farmers in the United States whose incomes are far larger. The tools used are limited in number and generally crude in design, but this is changing for the better. German plows and American mowers, hay rakes, and hay tedders were often seen. Almost as

many women as men were working in the fields, but they looked cheerful and contented. Everyone worked, from the gray-haired grandmother down to the 5-year-old who herded geese along the roadside ditches or on the banks of laterals.

THE VETTABBIA CANAL—OWNED AND OPERATED BY AN ASSOCIATION OF FARMERS.

On the south side of the city of Milan, among tall, stone business blocks and factories, is the head gate of an irrigation canal which has unusual historic interest. If tradition is to be believed, it is the oldest irrigation work in Lombardy and irrigates fields where marcite—the most profitable crop in Italy—was first grown. This canal was originally a natural stream formed by the confluence of three small creeks, the Savese, Nirone, and Vetra, which come together in what is now the city of Milan. Later on, when Milan grew into a fortified town surrounded by a wall and moat, these creeks emptied into the moat, for which the Vettabbia served as a waste way and drain. A few miles below the city the Cistercian monks had founded the monastery of Chiaravalle and brought under cultivation a large tract of land. The creek which flowed past it served as a sewer for the city and the water had an additional value as a fertilizer, and this may have had something to do with the construction of the small ditches which were built to water the landed properties belonging to the monastery. These small ditches were built about seven hundred and fifty years ago, and served as laterals to the winding, crooked, natural channel of the stream, to the waters of which the monastery gradually acquired rights by prescription and through successive grants from the popes and the German Emperor.

In 1156 the city had outgrown its original limits and the moat became an interior canal, which to-day is known as the "Ring Canal" around the central part of the city.

When the Martesana Canal was constructed, connecting the Ticino and the Adda rivers, it cut off the little creeks from the north of the city and the Martesana afterwards furnished the water for the interior canal and a considerable part of the water needed to supply the rights from the Vettabbia.

As time went on other religious communities, scattered along the 12½ miles of the Vettabbia between the city and its mouth in the Lombro River, had become aware of the value of water for irrigation and had in 1236, 1256, 1289, and 1311 applied for and received grants of rights to its use from the popes and the Emperor Frederick Barbarosa of Germany. In 1267 the health of the city was impaired because the crooked shallow channel of the Vettabbia furnished an imperfect drain for its sewers, and agreements were made with the monasteries of Chiaravalle and Viboldone to give them the right to

the sewage water if the monasteries would improve the channel to carry it away from the city and put it to use in irrigation, this being the earliest known example of the purification of sewage water by using it for irrigation. Out of these various agreements the irrigators from the Vettabbia Canal have acquired rights to water from the Martesana Canal, varying in ordinary times from 70 to 141 cubic feet per second; 706 to 1,059 cubic feet per second from storm waters, and 140 cubic feet per second from springs and sewage, making in all 1,340 cubic feet per second.

By subsequent changes these water rights passed out of the hands of the church authorities into the possession of an association of land owners, organized in the first place to maintain and defend the ancient water rights of the several users against each other and against outside parties and for improving the bed of the canal in order to stop waste and render better service. This association is composed of 50 voting members, some of whom represent smaller associations formed by irrigators along laterals, this being the prevailing practice under Italian irrigation works. The members of the main society pay each year a certain amount for expenses, and each member of the association is entitled to a certain definite amount of water. Whatever can be saved above this is sold to other irrigators. There are still lands needing water at the lower end of the canal and a ready market for whatever water can be made available. The purpose of the association is not, however, to make money from water rentals. These are now being utilized in improving the canal and for increasing the water supply by extending the drainage of Milan and the adjacent irrigated lands. The water derived from the ancient rights cost the association nothing, the Martesana Canal being compelled to deliver the water it furnishes free of all charges, and the city of Milan feels that it is a satisfactory bargain to get rid of its sewage waters without expense.

In 1889 a new drainage system was planned for the city, which made an agreement with the Vettabbia Association by which the latter obligated itself to enlarge the canal to carry away the increased drainage of the city, receiving in consideration for these expenditures a right to the municipal sewage and drainage water from 5,187 acres of land. The municipality pays all the expenses within the city limits and the canal association all of the expenses outside, and in this way each of the parties avoid making any payments of money to the other. The improvements on the canal cost about 2,000,000 Italian lire ($400,000), and include straightening and deepening the channel in places, putting in checks and drops to lessen the excessive grade caused by this straightening, paving, and cementing the canal where gravel beds are crossed, and replacing old and inaccurate measuring boxes by modules built under conditions which are intended to insure accuracy. It was necessary, as a part of this work, to construct a new canal, and

the drops, siphons, and flumes made necessary by the numerous railroads, tramways, and wagon roads crossed made the reconstruction a difficult piece of engineering. For this reason the work was placed under the direction of Luigi Franchi, one of the foremost civil engineers of Lombardy. Many of the structures are fine examples of engineering practice. By straightening and deepening the canal in places, it has been possible to drain large areas which had become swamped or were becoming so, and this has increased rental values.

Through the courtesy of Engineer Franchi, the water master and his assistant acted as guides in inspecting the improvements being made. Engineer Franchi also furnished a number of drawings of the new structures and furnished much of the historical data about the Vettabbia.

The head gate is of iron set in masonry. Just below it are two iron current wheels which turn power mills. The right to this use of the canal for power is one of the ancient concessions and costs the owner nothing except a small contribution to help pay operating expenses.

Within a few hundred feet of the canal head gate a set of steel regulating gates set in masonry permit all of the water received from the Martesana Canal to be turned into another ditch belonging to the proprietor of a large estate, who holds an ancient right to the water from the Martesana for a certain number of hours every fifteen days.

Some of the older measuring boxes were of the pattern shown in figure 4 (p. 30). Figure 12 shows a plan of regulating gates and orifices of one of the new measuring boxes which measures the water delivered to four farmers. Two of the boxes measure 2 oncias each, and two 4 oncias each. The depth of water in front of the regulating gates is determined by the height on the weir maintained at the drop. In these measuring boxes the cover which forms a feature of the old devices is omitted. The space between the regulating gates and the orifice is open, the weir at the drop being depended upon to keep a uniform depth of water against the regulating gates and in this way maintain the pressure of water above the top of the orifice. The appearance of this measuring box is shown in Plate VIII.

Plate IX shows a view of the reconstructed portion of the canal about 4 miles below Milan. It is walled with brick and cement and crossed by numerous concrete arched bridges.

In its substantial construction and excellent alignment the canal is a source of instruction and enjoyment to engineers. There are in Lombardy about 2,000 springs. These are the principal sources of water for marcite irrigation, because the water is warm in winter. It is more valuable than water from streams, and irrigators endeavor to keep rights to each spring separate from all other sources of supply. The consequence is that the whole country is crossed and recrossed by

MEASURING BOXES ON VETTABBIA CANAL.

Shown in fig. 12. *a*, Gates for regulating pressure; *b*, orifice in stone slab.

VIEW OF RECONSTRUCTED PORTION OF VETTABBIA CANAL.

The side wall and the bridges are of brick and concrete. The posts of the roadway guard are granite. The brush border along the roadway is a typical feature of the landscape in Lombardy.

these little individual ditches. The new line of the Vettabbia had to go over and around these as best it could. Figure 13 shows the canal crossing an irrigation ditch and a drainage ditch by means of two iron

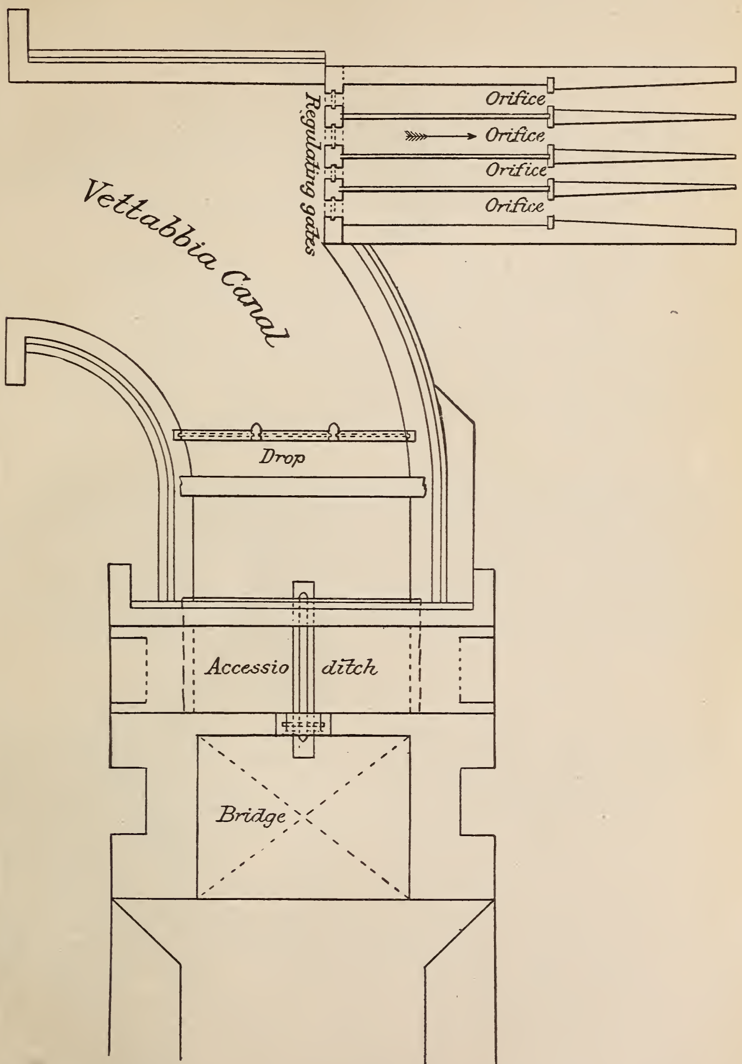


FIG. 12.—Section showing measuring boxes, drop, flume, and bridge crossing on branch of Vettabbia Canal.

flumes. Figure 14 shows a canal going under two other ditches by means of siphons, and also gives a small map of one of the places where about a dozen ditches interlace like a spider web.

In building these structures the earthwork excavation cost 7 to 11 cents a cubic yard; masonry, $2.70 per cubic yard; side walls of cement blocks, $3 per cubic yard; iron for bridges, 2 cents per pound; timber (American pitch pine or Oregon fir), $33.50 per thousand.

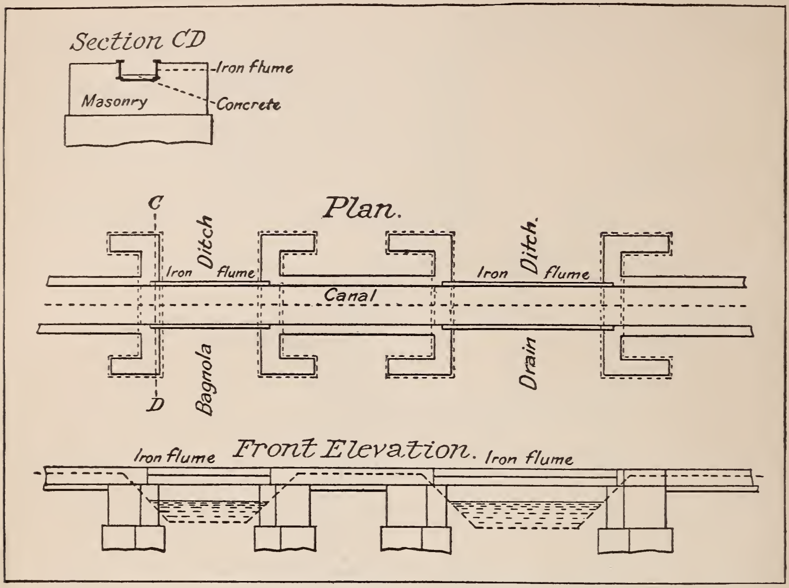


FIG. 13.—Branch of Vettabbia Canal passing over an irrigation and a drainage ditch.

FARMING UNDER THE VETTABBIA CANAL.

Some farmers under the Vettabbia have ancient rights entitling them to all the water they need for a certain number of hours each week or for a certain period during the season. Here the usual style of diversion is of brick or masonry flume, through which the flow of water is regulated by an ordinary wooden head gate. Accurate measurement of the value taken is not attempted. The quantity of water diverted depends largely upon the depth in the canal. One of these farmers had a right to water for twelve hours each week, beginning at 5 o'clock Sunday morning, and was thus compelled to violate the Sabbath. Another farmer had a right to 2.52 cubic feet per second, continuous flow, in the winter time, which he uses in irrigating marcite, and 5.4 cubic feet per second for a fifteen-hour period each week in the summer time. This period begins at midnight Wednesday and ends at 3 o'clock Thursday afternoon. The hour of beginning, the day of irrigation, and the number of hours have not changed for twenty years. This right is a free, perpetual one, and the owner paid $1,336 an acre for the land to which it is attached.

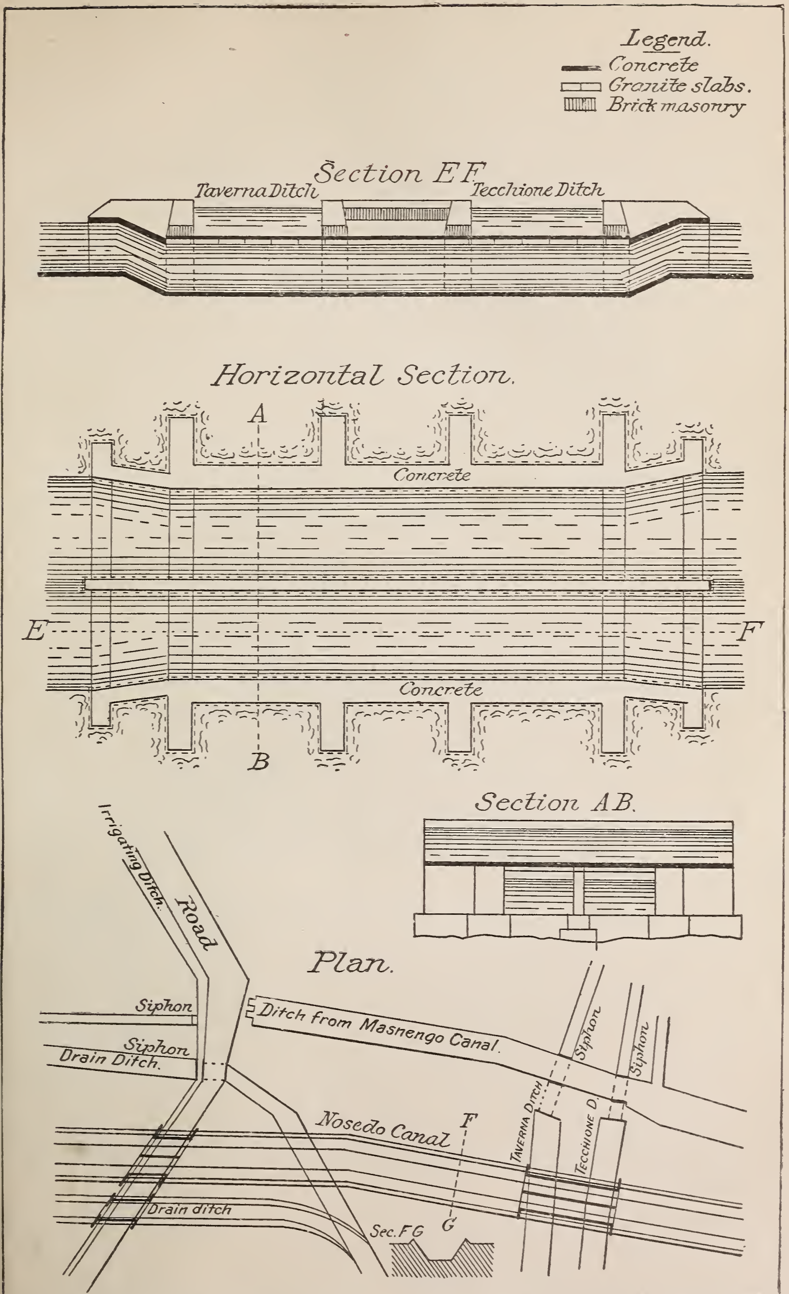


Fig. 14.—Vertical and horizontal sections and plan showing siphon for passage of the Nosedo Canal under the Taverno and Tecchione ditches.

The perennial water supply of the canal is sufficient to irrigate 8,400 acres of meadow and marcite and 3,500 acres of cultivated crops. The water coming to the canal from drainage in ordinary rain storms irrigates 5,200 acres of meadow and 2,200 acres of cultivated crops, while 7,400 acres receive waterings whenever floods are available.

The most important crop is marcite, a mixture of clover and Italian rye grass. Over this water flows almost continuously in winter and either continuously or at short intervals in summer. Summer irrigation extends from April to September. The grass is cut when it is about 18 inches high, and on some farms near the city 10 to 12 cuttings are made each year. Farther away from the city 6 to 8 cuttings are the rule. On one farm of 20 acres, where 16 acres were in marcite, 10 to 15 tons per acre was obtained at each cutting in 1903, and in the twelve months prior to my visit there had been 10 cuttings. The grass sold for $1.80 to $2.25 per ton, making the income from each acre about $300 per year. The farmer paid a yearly rental for land and water of $35.84 an acre. The land was valued at $3,000 an acre.

Another farm of 324 acres was divided about evenly between marcite and cultivated crops. The rotation on the cultivated portion was for a six-year period: First and second years, corn; third year, oats or wheat; fourth, fifth, and sixth years, hay, usually clover or alfalfa. The yield per acre on this farm for this year was estimated as follows: Oats, 53 bushels; wheat, 34 bushels; corn, 80 bushels. The corn crop was especially fine. Here, as elsewhere in Italy, the corn was planted much more closely than in the United States—too close, it seemed, for best results. However, the fodder value of the corn crop is far greater than in the United States, and to this their practice is doubtless due. Alfalfa is cut six times a year, and yields about as it does in northern California. The corn on this farm is irrigated, as a rule, three times a year. This year the farmer irrigated July 10, July 25, and August 15.

The preparation of marcite fields and their irrigation differs from anything in America, and hence is worthy of especial attention. In the first place, it needs to be understood that one of the purposes of marcite irrigation is to keep the fields green and the grass growing during the cold winter weather. For this reason the water in winter must be warm. The water from rivers is not suited to the purpose. The greater part of the water for marcite irrigation in Lombardy comes from springs, the total volume utilized in this way being estimated at 2,500 cubic feet per second. In addition, the city sewage and the heated water from the dyeing tanks of the silk factories are also utilized.

The fields on which marcite is to be grown are prepared so that water will flow continuously from the ditches in a very thin layer and the slopes are made so uniform that there are no bare spots and no pools. The system followed is to grade the land into a series of gently slop-

ing ridges. The supply ditches run along the summits of these ridges, while between are drain ditches for carrying off the water. These ridges are about 50 feet wide from one drain ditch to the next. The width varies, however, with the slope of the country. The ridges are, as a rule, about 300 feet long, but this again depends on the slope of the country. The supply ditches which run along these ridges are level from end to end, so that when full the water will flow over the edges on both sides throughout the entire distance. As the country has a gentle slope from the mountains toward the Po, there is always at the lower end of a ridge a drop, the aim being to give a fall of about 4 inches at each drop. This 4-inch fall gives grade to the drain ditches between the ridges. The drains are about 20 inches wide, deeper at the lower ends than at the upper, and at their lower ends there is a ditch which collects the water and carries it to the ditches on the ridges in the next step down the slope. In summer the water is turned over these fields as a rule from one to three days a week, and in winter it runs constantly. Where water is free from sediment, the ditches will last for many years, but along the Vettabbia Canal, where paper, straw, and city refuse are being constantly deposited, the lands have to be worked over, the ditches cleaned out, and the surfaces regraded every six or seven years.

Plate IV shows the location of supply and drain ditches on a farm near Vigentino. In this diagram the black lines show the drains and the blue lines the supply ditches. The section shows how the ground is graded in order that the water which overflows the supply ditches shall pass down the slopes into the drain ditches and be carried away. The principal marcite meadow on this farm is divided transversely from east to west into 5 squares or fields on different levels, one above the other, and is further divided longitudinally north and south by the ditch which carries the water from the Inferno Canal, forming thus 10 squares or fields of marcite. The 5 squares to the west are each divided into 8 "ale" (section between a lateral and a drain), and those to the east are divided into 16 ale, all straight from north to south. To the north of each square is a transverse ditch connecting with the above longitudinal ditch. The water comes from the Inferno Canal to junction No. 1. This being open, the water passes into the principal lateral from 1 to 2 and, entering the sublaterals of the sections, irrigates the first squares on the east and on the west. The second junction being opened, the water flows to the third junction, where it is checked and irrigates the second squares. This third junction being opened, the irrigation of the third square follows. In the same manner junctions 6 and 9 being opened, the fourth and fifth squares are irrigated. Finally, junction 12 being opened, the water discharges into the drain and passes to lower farms. The closing of gates 4, 5, 7, 8, 10, 11, 13, and 14 stops the irrigation of the corresponding

squares. It is thus evident that any one of these squares may be irrigated independently of the others.

The two springs shown on this diagram come from the gravel subsoil, which is about 10 feet below the surface. In order to increase the flow of these springs large areas of the gravel have been uncovered, as is shown by the blue surfaces in the diagram. Usually the principal flow is near the upper end of the excavation, which is triangular in shape and broadest at the end opposite the outlet. The source of these springs is not known, but they are supposed to come chiefly from the seepage water which sinks in the channels of the streams. Part of it doubtless comes from the irrigation of higher lands, the flow of many springs having increased fully 20 per cent since the construction of the Villoresi Canal.

In arranging for the irrigation of marcite fields, the rule is to provide 1 cubic meter of water per second for about 20 hectares. Thus 1 cubic foot per second will water 1.4 acres. Nearly all this water escapes in the drain ditches and can be used over and over again. After the first four squares are irrigated with water from the canal, those below are irrigated from the drainage. The grass in any of these squares having grown to the desired height (which requires on an average about a month, except in December and January, when only one crop is produced), it is prepared for cutting by withholding water for one or two weeks, during which time the water from the main canal is carried to the other squares.

The farms along this canal showed many evidences of the long-continued prosperity this region has enjoyed. One of the barns visited was six hundred and fifty years old. It was of brick, with massive rough-hewn roof timbers. The fields from which it is filled have been constantly used to grow marcite for the entire period. The tenant said that both the productive and rental value of this land has risen greatly in the last fifty years. In 1848 his father paid $7.20 an acre annual rental, while he pays $26.25 an acre. He ascribed this increase to two causes—drainage and increased fertility.

Dairies are nearly everywhere an adjunct of marcite meadows. Over 100 cows are kept on this farm; these are mostly Swiss cattle and are valued at $100 to $135 a head.

THE SEWAGE OF MILAN.

The sewage water of a part of Milan has been discharged into the Vettabbia and used on the lands under that canal for centuries. The sewage from part of the city having 150,000 inhabitants is at present used upon an area of 6,788 acres, more than 5,000 acres of which is marcite meadows. These meadows, unlike the sewage farms of other European cities, are not cultivated, and it was thought by many that their use as a means of sewage purification was detrimental to the health of the region and might prove injurious to agriculture. In

1900 the city of Milan appointed a commission to inquire into the whole matter of sewage disposal. A subcommission was charged with the investigation of the hygienic and agricultural effect of the use of sewage in the irrigation of marcite. The work of this commission included analyses of the water before it was applied to the land, and as it flowed from the meadows; analyses of water from springs and wells; analyses of the soil on which the water had been used; and inquiries into the records of disease and mortality, and of crop returns.

The soil on which the sewage is used is disintegrated rock resting on a bed of sand and gravel, and is therefore favorable to the filtration of water. Marcite meadows have the advantage of using water throughout the year, but the disadvantage of not being plowed so as to bring the sewage water in contact with fresh soil. It was found that a part of the filtration took place in the soil and a part through the grass. In marcite irrigation the water is used upon several squares in succession, that draining from the first square being collected in drains and applied to the second square, and again collected and applied to other lands (see p. 66). It was found that muddy water applied to the first square came off nearly clear and after flowing over two or three squares was perfectly clear, free from odor, and without any of the impurities contained in sewage water. From the standpoint of the purification of the water its use in marcite irrigation is entirely successful.

It was found that there were bare spots in the meadows on which a coating of algæ had formed, preventing the growth of grass, and that paper and other refuse collected in places sufficiently to cause some inconvenience, but the commission was of the opinion that both of these could be prevented by care in cleaning the canals and in the use of water. Analyses showed that in places where the soil contained no lime there was a tendency for organic matter to accumulate to a harmful degree. This condition can be corrected by the application of lime, and the commission recommends that course.

Analyses of water from wells and springs showed that there was no contamination from the sewage water, and careful inquiry and examination of records showed that the sanitary conditions under the Vettabbia were not different from those in other sections.

The general conclusions of the commission were that the water is thoroughly purified; that there is no danger to health; that from an agricultural standpoint there is some trouble, but it is of little importance and can be overcome with proper care. It is recommended that in order to maintain these conditions there should be one acre of land to every 36 inhabitants, and in no case less than one acre to 60 inhabitants, and that provision should be made for diluting the sewage water to such an extent that the nitrate content shall not exceed 120 milligrams per gallon. If these conditions are observed there will be no danger in the use of sewage water.

Chapter III.

IRRIGATION IN PIEDMONT.

The water supply—State irrigation works in Piedmont—Engineering features of the Cavour Canal—Administration of canals—Rates for water—Vercelli Irrigation Association—Settlement of water rights—Agriculture in Piedmont—Duty of water—Measurement of water.

From Milan, the capital of Lombardy, to Turin, the capital of Piedmont, is a railway ride of four hours, nearly the whole distance being through irrigated farms. On crossing the Ticino River the mulberry groves of Lombardy give way to the rice fields of Novara and Vercelli. The railroad crosses several branches of the costliest Government canal in Europe, which makes irrigation in Piedmont a matter of special interest to engineers throughout the world. The Government engineers of both the public works and treasury departments have their headquarters in Turin, and the School of Engineers of Piedmont is also located in this city.

About 10 per cent of the 11,400 square miles of Piedmont's territory is irrigated, much of the remainder being mountainous. The irrigated lands begin close to the foothills, about 1,000 feet above sea level, and extend down to the Po, 200 feet above sea level. But little land is irrigated on the south side of the Po, since the foothills border it closely—at Turin the river flows directly against their base—but farther east there is a narrow valley which is watered by a large Government canal with a pumping plant to lift the water onto land which can not be reached by gravity. On the north side of the Po the slope of the country is in two directions—about 5 feet to the mile from west to east and about 8 feet to the mile from north to south, the slope being somewhat greater close to the foothills and flattening out toward the river. The irrigated land is served by both private and Government works, Piedmont exceeding all other Italian provinces in the number and importance of its State canals.

The climate of Piedmont is drier than that of Lombardy, the average annual rainfall being nearly 25 per cent less. The 40 inches at Milan drops here to 31.1 inches. This, however, is larger than the rainfall of much of the humid portion of the United States, and its distribution is as favorable to the growth of crops as that of many sections of the

Mississippi Valley. The largest rainfall occurs in the summer months, the average percentage for the four seasons being as follows:

Distribution of rainfall at Turin.

	Per cent.
Winter	14.7
Spring	26.3
Summer	31.6
Autumn	27.4

THE WATER SUPPLY.

There are two classes of streams in Piedmont, those which rise in the foothills and are fed by rains and snows and those which extend back into the high mountains and are fed largely by glaciers. The foothill streams have their floods in the spring and are very low in midsummer. The glacial streams carry little water in the winter and early spring because of the intense and long-continued cold of the high valleys, but in the summer time the hotter the weather the more rapidly the glaciers melt and the more water there is to supply the canals in the valley. The Po, Sesia, Elvo, and Cervo rivers belong to the first class. The Dora Baltea and the Ticino are typical streams of the second class.

The water from the foothill streams is preferred by irrigators whenever it can be had. It is warm in the spring and as a rule carries considerable fertilizing material. The Po, Elvo, and Cervo rivers are always warm enough to be used. The water of the Po is of the color of ocher, resembling in that respect the Sacramento, and the sediment deposited on the fields is highly valued by farmers because of its fertility. On the other hand, the streams fed by the glaciers are too cold to be used in the early spring. Cakes of ice sometimes travel the entire length of the canals diverting the Dora Baltea. The water of the Ticino carries no silt whatever, hence has no value as a fertilizer. The water of the Dora Baltea is gray in color and looks like the tailings from a stamp mill. Its sediment is formed by the grinding of the glaciers over granite and has no value as a fertilizer, although it has in cementing the canals. Seepage losses are not a serious factor along the Dora Baltea because of this.

The lowest discharge of the Po at Chivasso is 1,412.4[a] cubic feet per second. This occurs in July and August, continuing about six weeks. Only once (in 1882) has its discharge been as low as 989 cubic feet, and this continued for only fifteen days. The mean annual discharge is not less than 2,471.7 cubic feet per second.

The low-water flow of the Dora Baltea continues from October to May and varies from 1,000 to 1,800 cubic feet per second. The high-water period, during which time the water is very turbid, continues

[a] The decimals in this and succeeding numbers come from reducing from Italian to English units.

from May 15 to the middle of September. The flood period is usually in July and August. When the river is high the Government canals take 5,649.6 cubic feet per second, and 1,765.5 cubic feet per second is diverted by private canals.

The Sesia River and its tributaries, the Elvo and Cervo, furnish 1,765.5 cubic feet per second to the Government canals from October to June. From June to September this discharge is reduced to 706.2 cubic feet per second.

The following is approximately the amount of water diverted and used in irrigation in Piedmont between the Dora Baltea and the Ticino rivers:

	Cubic feet.
From October to May:	
From the Po at Chivasse	3,177.90
From the Po at Casale	353.10
From the Dora Baltea	1,412.40
From the Sesia, Elvo, and Cervo	1,765.50
From springs	353.10
Total	7,062.00
From June to September:	
From the Po at Chivasse	2,118.60
From the Po at Casale	353.10
From the Dora Baltea	5,649.60
From the Sesia, Elvo, and Cervo	706.20
From springs	529.65
Total	9,357.15

STATE IRRIGATION WORKS IN PIEDMONT.

As formerly used neither class of these rivers exactly met the requirements of the irrigators depending upon them. Farmers along the glacial rivers were often short of water in the spring or were compelled to irrigate when the water was so cold that the growth of crops was checked. The farmers along the foothill streams, on the other hand, had more warm water in the spring than they could make use of and suffered from droughts in midsummer. It was realized that if the water of the foothill and glacial streams could be mixed so that irrigators could be served by the foothill streams in winter and spring and by the glacial rivers in summer, it would add immensely to the profits of agriculture. This could be done by building a canal which would run along the foothills almost parallel to the Po, intercepting the different rivers flowing down from the mountains into it in such a way as to use them for feeders or to turn the water into them as conditions might require.

The project of building such a regulating canal was first publicly advocated in 1633. A number of lines were surveyed, all starting from the Po but crossing the plain and the tributaries at different elevations. The canal finally built follows the surveys of the distin-

guished Italian engineer, Carlo Noe, and the credit for carrying out the project is largely due to the enterprise and persistence of Count Cavour, for whom the canal was named.

The canal starts on the north bank of the Po, about 15 miles below Turin, near the little town of Chivasso. It crosses the Dora Baltea River 2½ miles east of this on an arched masonry aqueduct, goes under the Elvo and Sesia rivers by means of inverted siphons, and, after crossing a large number of canals and smaller natural streams, finally ends on the west bank of the Ticino. Its principal water supply comes from the Po and the Dora Baltea and it serves as a reserve supply for the Elvo, Cervo, and Sesia rivers in midsummer. Running as it does, almost at right angles to the streams flowing down from the Alps, and having been built after the whole country had been brought under irrigation by canals diverting these rivers, it crosses not only the natural streams but a very large number of the older canals. When it was built one great source of expense was arranging for these canal crossings. Some of the canals were connected with it from the outset and others have been brought into connection, so that now the prevailing plan is to let the canals which start from these rivers above, where the Cavour Canal crosses them, empty into the Cavour and then fill them again from head gates on the lower side. By having all the higher canals empty into the Cavour the water from the cold and warm streams is thoroughly mixed and irrigators below have the advantage of water at a satisfactory temperature throughout the year. The Cavour, therefore, has connected with it an immense system of subsidiary canals feeding it and drawing water from it. The water it takes directly from the rivers is consequently only a fraction of the quantity it receives and discharges. To keep an accurate record of the water received from streams and canals and that turned out to other streams and canals is an undertaking in water measurement more complicated and important than any yet required on any irrigation system in the United States. The combined capacity of the Cavour Canal and its connections is 10,240 cubic feet per second, the capacity of the different canals in the system being as follows:

Capacity of Government canals in Piedmont.

	Cubic feet per second.
Cavour Canal (Po)	3,884.10
Lanza Canal (Po)	353.10
Gazelli Canal (Po)	70.62
Ivrea Canal (Dora Baltea)	706.20
Depretis Canal (Dora Baltea)	1,942.10
Rotta Canal (Dora Baltea)	635.58
Canals from Elvo and Cervo	353.10
Busca Canal (Sesia)	776.82
Rizzo-Biraga Canal (Sesia)	635.58
Sartirana Canal (Sesia)	882.80

The present extent of the Government system is shown by the following statistics:

Length of Government canals in Piedmont.

	Miles.
Total length of main canals	282
Distributing canals	177
Secondary canals	467
Total	926

HISTORY.

The system of irrigation works of which the Cavour is the basis has its offices in Turin, where Engineer Mazzini, who has charge of its administration, arranged for a week's inspection of the canal, to begin at the head gate at Chivasso and include the irrigated land in the provinces of Vercelli, Novara, and Mortara. It will aid in understanding the system to give something of the history of its evolution, as a partial understanding of the vicissitudes undergone in the past is necessary to a comprehension of the existing situation. Water rights and the ownership of canals in eastern Piedmont have been closely interwoven with the political and financial fortunes of the country's rulers. This can be illustrated by the early history of a few of the canals belonging to the present system of State works.

The first of these was begun in the twelfth century at what is now the head of the Ivrea, and was completed in 1468. It was abandoned a century later on account of the difficulty of keeping it from filling with sand. In that disused condition it came, two hundred years later, into the possession of the Prince of Francavilla, who cleaned it out and again used it for irrigation and navigation. It remained one of the possessions of this princely house until 1820, when it was purchased by the State from the noble house of Solaro del Borgo, to whom it had descended by inheritance. One of the chief sources of revenue from this canal when it was in private ownership was the furnishing of power to mills, especially flour and rice mills. In its 46 miles it runs through 14 towns and cities. The industrial contracts made with the mills in these towns, as well as many of the contracts entered into by the noble houses with farmers, have to be respected by the Government, and these have an important influence upon the methods of distribution employed.

Another canal which illustrates the evolution of the present system is the Sartirana. It is the lowest diversion from the Sesia and was begun in October, 1387, the right to water being given to Beneventano de Tortis by the reigning Duke Galeazzo Maria Visconti. The grantee of this right was authorized to take as much water from the left bank of the Sesia River as was necessary for the irrigation of the territory of the Sartirana, and *for all of the lands on which the grantee could use*

it conveniently. De Tortis gave this right away and the gift was confirmed by Francesco Sforza I by a decree of May 1, 1452, which was followed by a quitclaim deed from the heirs of De Tortis in 1455. The sales of water rights in America have, therefore, abundant precedent in the early history of irrigation in Italy.

A flood in the Sesia in 1457 destroyed the dam and another was afterwards built at a different place. Financial troubles of its owners caused its confiscation and it passed to the Duke of Bari in October, 1479, by a concession from the Duchess Bianca Visconti. In 1494 it became the property of the Duke of Milan. This duke was defeated by Louis XII of France in 1497, was imprisoned, and his property given to the Cardinal of Amboise. When the French were defeated, the canal was taken away from this cardinal and again given to the Duke of Milan. The latter gave it to Cardinal Gattinara and it remained in the Gattinara family until acquired by the State under the law of July 19, 1857.

Before this canal was even begun, the right to the water as it ran in the natural channel had been given away, sold, and leased several times. In its subsequent history, the part of the river controlled by the grant was the property in turn of nobles, priests, and kings. The men living along the 20 miles of its length, and who each year spread its 882 cubic feet of water per second over their fields, had to deal in succession not only with their changing local rulers, but with foreign ones in Milan, Rome, and Paris.

In acquiring this canal, the State had to assume the obligation of supplying free of all charges certain perpetual rights. During the five hundred years of its changing proprietorship, whenever an owner was in pressing need of money, the sale of a free perpetual right was one of the surest means of obtaining it. The money thus paid did not go into the betterment of the canal, but did impair forever after its income, and when the State became the owner of the property these free rights became a burden on the community. In most cases the supplying of these free rights is a source of irritation to other water users from the canal, because they not only have to pay large assessments for keeping the canal in order, but their rights to receive water are inferior to those of the men who pay nothing either for the water itself or for the expenses of its delivery. The rights sold in this canal include the water supplied to several individual ditches and power to four mills and several industrial establishments. Since the canal became State property there has been an important addition to its income from power, 600-horsepower being furnished the electric-light plant of the town of Casale.

The advantages of uniting the different water supplies and operating a large number of canals as one system had long been manifest. The Government constructed the Depretis Canal as a means of supplying

the higher lands, and as early as 1820 had purchased the Ivrea Canal. The creation of one comprehensive system, however, made little substantial progress until 1840. At this time the needs of irrigation had become so great that farmers were insistent on more water and additional canals. In response to this demand the Government in 1846 arranged to purchase the Gattinara Canal, but the purchase was postponed by the war of 1848 and 1849.

Previous to 1853 farmers had little benefit from Government ownership of canals. The properties belonging to the State were farmed out to speculators, who were given a free hand to make whatever terms they could with the irrigators. These canal lessees, having no permanent interest in either the canals or the success of agriculture, often charged oppressive rates for water, which farmers, having no other source of supply, had to pay. In 1853, however, the Government put an end to this practice. A cooperative society of farmers was organized, which included all the users of water from the State canals between the Dora Baltea and the Sesia. This society of irrigators rented the canals directly from the State and did away with the speculative middlemen.

In addition to uniting the canals in one system this society aimed to bring about certain other reforms. State waters were not distinguished from private waters. The discharges of canals were unknown. There were no definite tariff rates for water. An irrigator could not tell one year what he would have to pay the next. Out of the association of farmers, begun in 1854, came the following results:

Purchase by the State of the Molinara Canal; purchase of the properties and canals belonging to the Mauriziano Order; acquirement of the canal and the water rights belonging to the Vercelli Hospital; acquirement of the Vercelli Canal belonging to the municipality; acquirement of the French canal belonging to Scappa Brothers; acquirement of the Sartirana Canal and the Gamarra Canal from the Marquis of Breme; authorization of the expense necessary for the enlargement of the Cigliano Canal; acquirement of the diversions from the Elvo and of the water rights belonging to Count Avogadro of Casanova; acquirement of the water rights belonging to Count Avagadro of Quinto; acquirement of the Marcova Canal belonging to the Count of Maistre.

The purchase by the Government of these canals was only one feature of the scheme for the extension of irrigation, and was subsidiary to the larger project of building a main canal to furnish an additional water supply from the Po River, which, crossing the drainage lines of the country, would serve as a feeder and equalizer for both rivers and ditches. When active work on this canal was begun in 1840 the idea was over two hundred years old, having been first proposed in 1633. It did not, however, take distinct form until presented

to the Government by Francesco Rossi, a civil engineer of Vercelli. The plan of Rossi secured the support of Count Cavour, who was not only the foremost friend irrigation has ever had in Italy, but one of the ablest statesmen of modern times.

To divert a torrential river like the Po and to carry a great canal over a river like the Dora Baltea, and under another, the Sesia, was a stupendous undertaking, and the country, impoverished by the expenses of the struggle with Austria for independence, was in no condition to carry it out directly; but Count Cavour persevered and his engineering assistant, Carlo Noe, completed the surveys and prepared a definite project for its construction in 1854. The wish of Count Cavour was that the Government should construct the canal, but the wars of 1859, 1860, and 1861 delayed this, and in 1861 Count Cavour died.

Not having the money to build the canal, the Government in 1862 made a contract with a syndicate of English and French capitalists, by which it sold to this syndicate all of the canals taking water from the Dora Baltea, Elvo, Cervo, and Sesia rivers, then owned by the State, for $4,060,000, the company, however, being obliged to respect all of the ancient rights in these canals and to carry out the Government's contract with the farmers' association at Vercelli. It was estimated that to pay for the State works and build the Cavour canal to serve as a connecting link between them would require an outlay of $16,000,000. The Government agreed to aid in securing these funds by guaranteeing for fifty years the payment of 6 per cent interest on this amount of bonds. With this guarantee behind them, it was expected that the bonds could be sold for enough to pay the State for its properties, purchase some additional canals needed, and build the Cavour Canal. In consideration of the Government's guarantee, the company agreed to turn over to the State at the end of fifty years the entire property free of debt.

The prospects of the company at the outset were such as to justify confidence in its success. With its interest payments guaranteed for a half century at a rate greater than that of most Government securities, and with a large number of irrigation canals already in successful operation, it would seem that the project ought to have been a financial success; but there were certain factors connected with the enterprise which apparently foredoomed it to failure. In the first place the company was crippled by the fall in price of Government securities. When negotiations began, Italian Government bonds were selling at 95. When the company was ready to sell its bonds they had fallen to 60, and before they were all sold the price had fallen to 40. Because of the heavy discounts which had to be made, only $11,200,000 was realized from the $16,000,000 worth of securities sold.

At first it was thought that the Po would furnish all the water

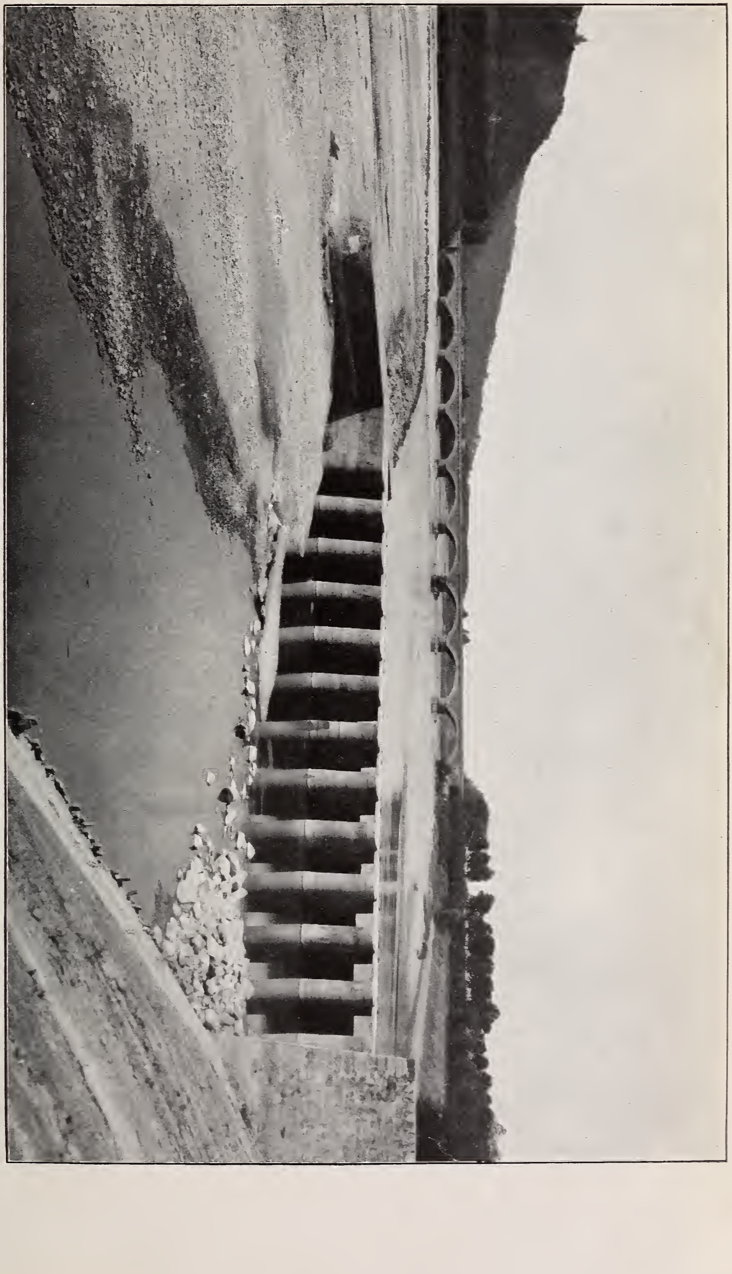
needed. Afterwards it was found that a supplemental supply would have to be drawn from the Dora Baltea, and that the diverting canal from that river would increase the cost of the entire work from $7,000,000 to $10,660,000. Of the estimate of $16,000,000, $1,200,000 was to pay for private canals and the construction of additional canals to distribute the water from the Cavour Canal. The difficulty of obtaining money to meet the construction expenses of the main canal led to delay or neglect in the construction or purchase of these distributing works, and when the main canal was finally completed there was a lack of laterals to receive and distribute the water. The company was unable, therefore, to carry out its agreement with the irrigation association at Vercelli, and the association had the option of terminating its contract. This, with the financial difficulties of the company, added to its inability to sell bonds, caused it to be declared bankrupt in 1867, and for practically three years the whole project was tied up in litigation and other complications.

When the main canal had been completed, at an outlay of more than $10,000,000, only about one-tenth of the water could be disposed of. The small revenue which this produced would not pay the interest guaranteed by the State, and as the canal had not been built in accordance with the specifications, the Government refused to pay this. In the suit which followed the Government was defeated, but the bankruptcy of the company and the complications and controversies which beset it led to the creation of a commission in 1870 to determine what the Government should do. The Government took over the property under the law passed in June, 1874, together with the other canals which it had originally owned and those which had been built or bought as a part of this system. For the last thirty years the canal has been operated as a State work.

ENGINEERING FEATURES OF THE CAVOUR CANAL AND CONNECTED WORKS.

The national road from Turin to Casale crosses the Po about 15 miles below the first-named city. The head gate of the Cavour Canal is about a quarter of a mile below the bridge on this road. As originally planned, the water was to be turned into the canal by means of a masonry dam extending entirely across the stream, with a series of sluice gates close to the banks on the canal side to scour out the sand and keep the head of the canal from filling up. The only part of this structure completed was the sluiceways, shown in Plate X.

In the place of the permanent masonry dam, a temporary diversion weir has been built by driving two rows of piles, placed 3.28 feet apart and 4 feet apart in the rows, in a curved line extending diagonally upstream. The space between the rows of piling is filled with huge blocks of granite, and smaller stones have been thrown in as riprap-



VIEW OF THE RIVER PO AT THE HEAD OF THE CAVOUR CANAL.

Sluiceway for scouring out sand in the foreground at right. Temporary diverting weir extending from end of sluiceway (on left) in curve across channel. Arched masonry bridge on national road above.

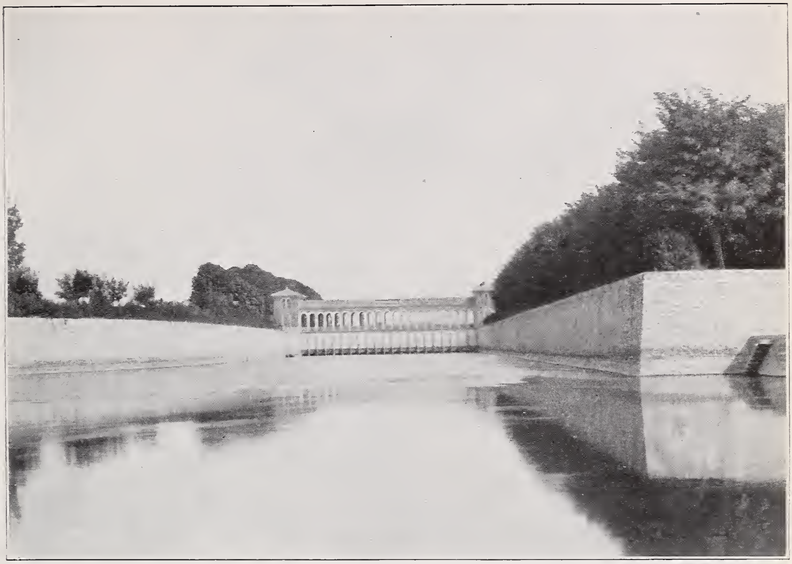
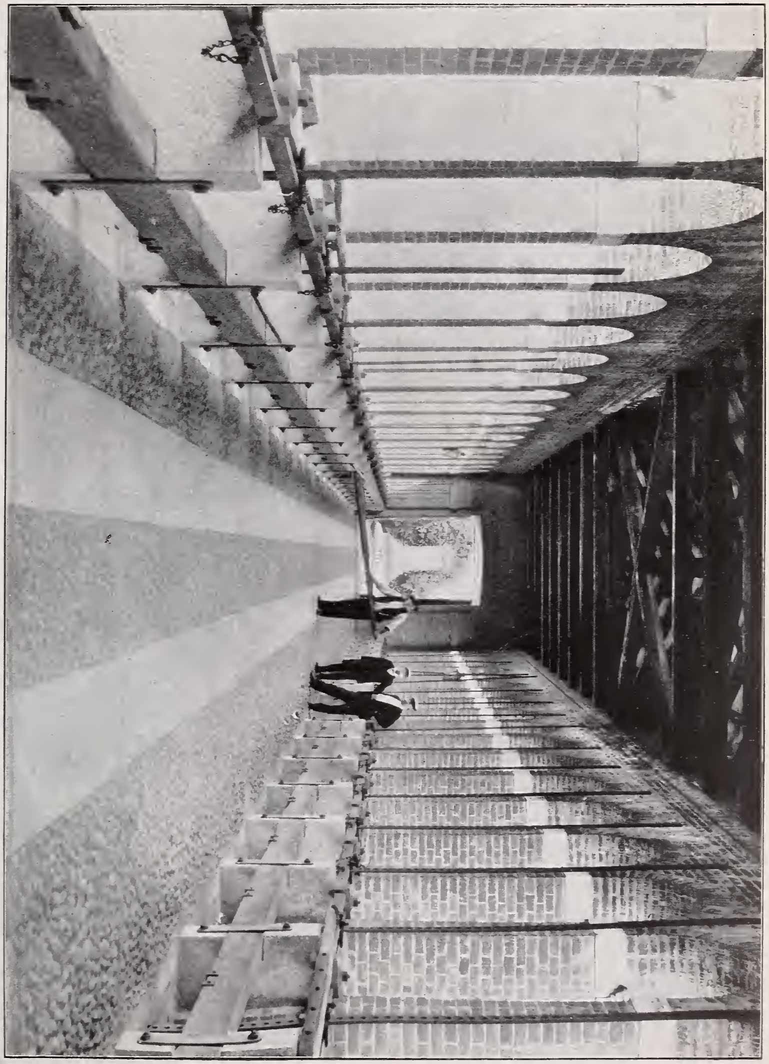


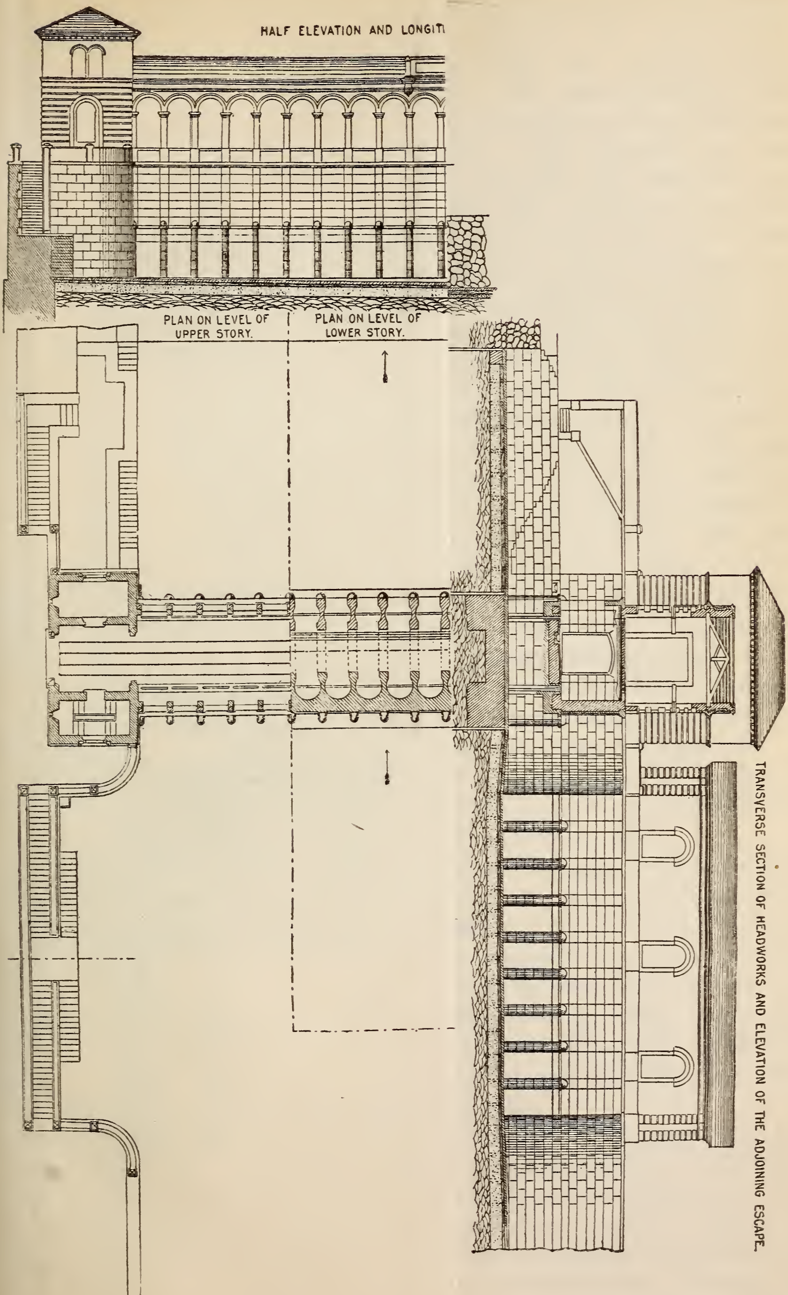
FIG. 1.—VIEW OF HEAD GATE OF CAVOUR CANAL, FROM ABOVE.
Sluiceway shown in Pl. X starts wall at right.

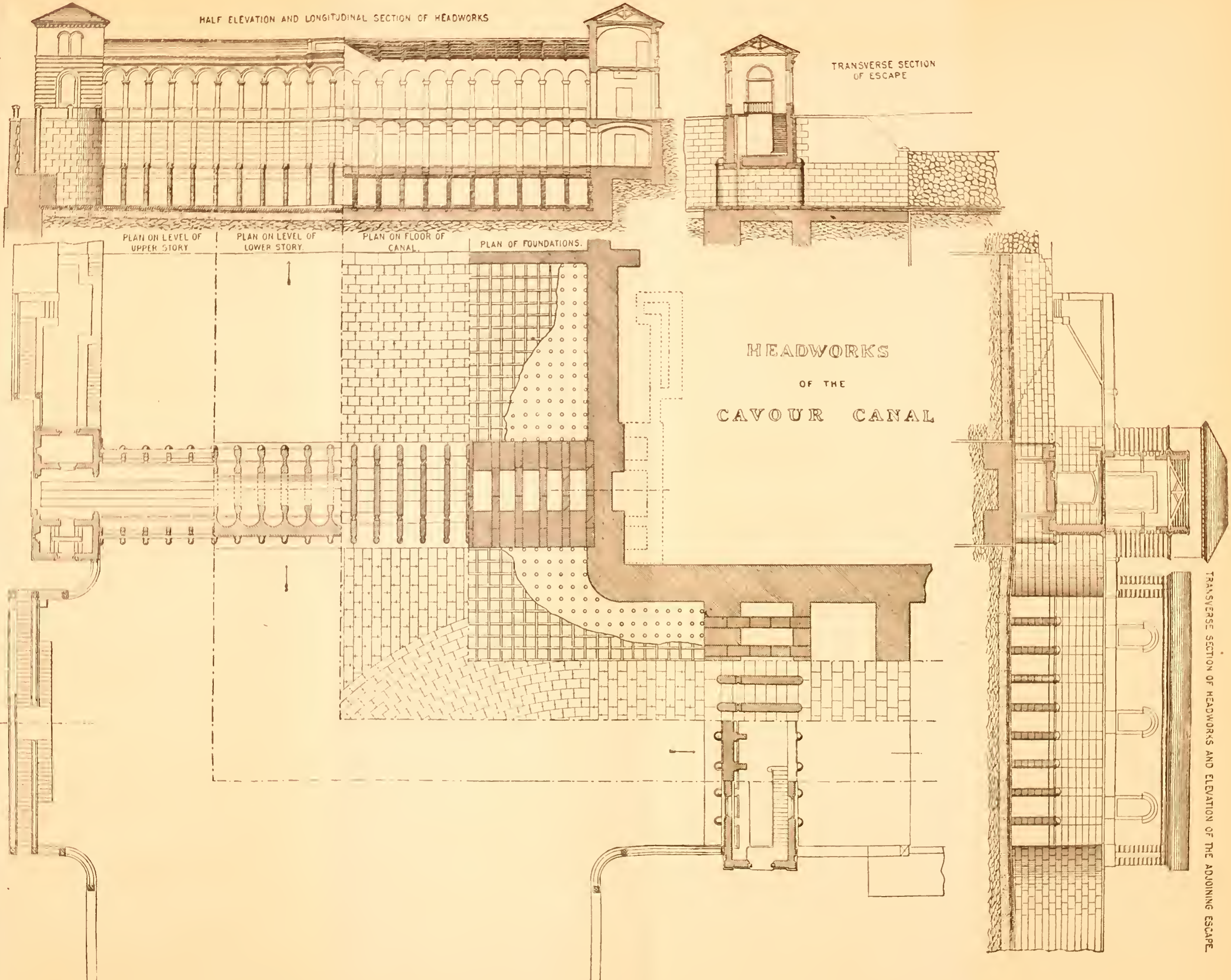
FIG. 2.—MASONRY FLUME CARRYING CAVOUR CANAL OVER DORA BALTEA RIVER.



INTERIOR VIEW OF THIRD FLOOR OF HEAD GATE, CAVOUR CANAL.

Man in center is operating lever which lifts the gates.


HALF ELEVATION AND LONGIT
PLAN ON LEVEL OF UPPER STORY.
PLAN ON LEVEL OF LOWER STORY.
TRANSVERSE SECTION OF HEADWORKS AND ELEVATION OF THE ADJOINING ESCAPE.



HEADWORKS OF THE CAVOUR CANAL

ping on both the upper and lower sides. The piling does not extend more than halfway across the stream. Beyond that it is intended that during flood time all obstruction to the water shall be washed out and then replaced when the river falls. The replaceable section had been restored at the time of my visit, and was made of stone blocks and bags of coarse wire filled with bowlders. This diversion weir had been extended out from the end of the rock-pile dam when the river fell below its crest. The wire bags filled with bowlders are an excellent expedient for this, owing to the ease with which they can be handled. They can be filled at the point where they are to be dumped into the stream, and when rolled in they are less liable to be moved by the current than blocks of stone. In front of these bags of bowlders sand bags had been thrown, making a water-tight dam, so that the entire flow of the river was being turned into the canal. The sluiceway next to the canal consists of granite masonry piers, resting on a concrete foundation, with 14 openings 4.5 feet wide and 8 feet high. The openings in the sluiceways are closed by means of oak planks, which are dropped into grooves when the river is low, and taken out when it is high, exactly as is done in similar structures in the West. The head gate is set back into the canal 700 feet from the river. The variation between high and low water in the river is about 25 feet. This has made it necessary to raise the banks and protect them by means of a high and heavy retaining wall of cut granite, adding greatly to the expense. In view of this expense and the greater difficulty of keeping this 700 feet at the mouth of the canal clear of sand, the reason for locating the head gate so far from the river was not apparent. It seems as if it would have been cheaper and better to place it close to the river bank, where the sluiceway in the diversion weir would have been more effective in keeping sand away from the gates.

The head gate is of an imposing and monumental character appropriate to a great public work (Pl. XI, fig. 1). At the west end of the head gate there is a beautiful bronze statue of Count Cavour, mounted on a marble pedestal. The base of this is shown beyond the doorway of the head gate in Plate XII. Plate XIII shows the elevations and foundation plans of the head gate, the drawings being reproduced from a report on Italian irrigation by Colonel Moncrieff. Plate XII shows an interior view of the third story of the head gate, the superintendent being in the act of lifting the gates.

The water is admitted into the canal through 21 openings, each 4.92 feet wide and 7.2 feet high, separated by granite piers 1.3 feet thick. There are two sets of gates, one at the front and the other at the back of the structure, the purpose of the double set being to relieve the pressure in operating them when the river is high and as a precaution against accident. Above the openings is a second story, in which the masonry on the upstream side is solid, as a precaution against floods,

which sometimes attain a height of 25.5 feet. The third story is both a bridge for crossing the canal and a gallery where the gates are operated, iron stems extending from the gates into this gallery. The gates are operated by means of a lever, and are held in place by pins inserted in the stems (Pl. XII). On the east side of the gates is a second wasteway having 9 openings each 5.5 feet wide and 10 feet high. The floor of this wasteway is 1 foot below the canal gates, and some of the openings are always kept open to aid in scouring out the sand.

On the day the head gate was visited all the water of the Po was being turned into the canal. Below the temporary dam the channel was a bed of dry sand, and the only water which appeared was perhaps a cubic foot per second leaking through the sluiceways, shown in the right of Plate X. Forty-three cubic meters, or 1,518 cubic feet, per second was passing through the head gates, which is a little less than half of the 90 cubic meters (3,178 cubic feet) per second which the upper section of the canal was built to carry.

The total length of the canal is 51.1 miles. At the head it is 131 feet wide on the bottom, and is planned to carry water to a depth of 8.2 feet. The width gradually diminishes. One and eight-tenth miles from the head the canal is 82 feet wide on the bottom, the sides are inclined 45 degrees, and it carries water to a depth of 11.25 feet. Two and one-half miles below the head gate the canal crosses the Dora Baltea River on a massive and beautiful masonry aqueduct 656 feet long and 45 feet high. It is supported on 9 arches built of granite masonry and resting on concrete foundations 5 feet thick. The arches, sills, and spandrels are of brick with joints of cement. The width of the water channel is 66 feet. The side walls are 12 feet high and 5.75 feet thick (Pl. XI, fig. 2).

The water of the Po is especially desired by irrigators because it is warm, and because the sediment has great value as a fertilizer, hence all that can be diverted is taken out in midsummer. But this is not sufficient and a considerable part of the supply must be taken from the cold glacial waters of the Dora Baltea. The Farini Canal was built to provide this supplemental supply. Its head gate is about 3 miles above where the Cavour Canal crosses the river, and is very similar to the head gate of the Cavour. A submerged concrete dam 656 feet long extends across the river, making it possible to turn the entire flow of the stream into the canal whenever necessary. When the river is high this dam causes great pressure against the head gates and water is forced through the openings with such velocity as to cause much damage, and a heavy outlay has been necessary to protect the sides and bottoms of the canal below the head gate, which are now lined with substantial granite paving for several hundred feet. Beyond that the bottom is lined with large stones thrown in loosely.

The head gate is divided into 9 sections by interposing piles, each part surmounted by an arch having a span of 10.5 feet with a rise of 1 foot. Each of these 9 sections is divided into two equal parts by a pillar of hewn stone in such a way that there are 18 openings with a width of 4.5 feet each. The gates are 9.5 feet high, and are operated in the same manner as those on the Cavour. Above the gates the structure consists of two galleries, the lower one being closed on the upstream side, but open on the lower side. The upper gallery is used to operate the gates. The total height of the gate structure is 38 feet and the width 78.5 feet, and the cost was $29,000.

The Farini Canal is built to carry 2,472 cubic feet per second. The Cavour was delivering 4,590 cubic feet per second when visited. Of this 1,518 cubic feet per second came from the Po, 2,472 cubic feet per second from the Dora Baltea through the Farini Canal, and 600 cubic feet per second from the Ivrea and Cigliano canals. In order that the management may keep informed regarding the quantity of water being received from the different sources and delivered to the different branches, every inlet and outlet gate has a float connected with an electric register which notifies the superintendents of the rise or fall of the water beyond certain limits. In addition to this, all branches of the system are connected by telegraph and telephone lines, so that what is taking place in every part of the 51 miles of the main canal is known at headquarters.

OTHER CANALS ALONG THE DORA BALTEA.

For 6 miles above the head of the Farini Canal the river bluffs border closely the west side of the Dora Baltea, but there is a broad valley bordering the eastern side. The bottom lands have luxuriant crops of corn, clover, and alfalfa. Considerable marcite is grown on the uplands, but the slope of the land is too great to permit the supply ditches to run down it as they do around Milan. They have to run across the slope, and water is distributed from one side only of the supply ditches. At the foot of the slope, about every 100 feet, there is another parallel ditch which catches the water from the slope above and turns it over the slope below. Although the losses by seepage from all the canals diverting the sediment-laden waters of the Dora Baltea were far less than from those diverting the clear water of the Ticino, the duty of water in this section is not appreciably higher than in Lombardy, where these seepage losses have to be sustained. One farmer who cultivates 200 acres buys 1.65 cubic feet of water per second. This gives a duty of 121 acres for each cubic foot per second, almost the same as that under the Villoresi Canal near Corbetta. This, however, is above the average duty. Where water is not paid for by the farmer it does not serve more than half the above area, and this is

32656—No. 144, pt 1—04——6

the prevailing condition in the country bordering the river, where many of the canals have ancient rights giving them all the water they can use. The Government canals provide water more liberally in this section than elsewhere, and the injurious effects of this liberality were shown in the neglected laterals.

One of the interesting canals of this region is the Rotto. The inscription on the gatehouse at the head states that it was built in 1400 by the Duke of Monferrato. The structure is of brick and shows the marks of age. The gates are primitive, and are lifted by a crowbar inserted in slots in the stems. It has the earliest right on the stream, and is entitled to 275 cubic feet per second.

PUMPING WATER FOR IRRIGATION.

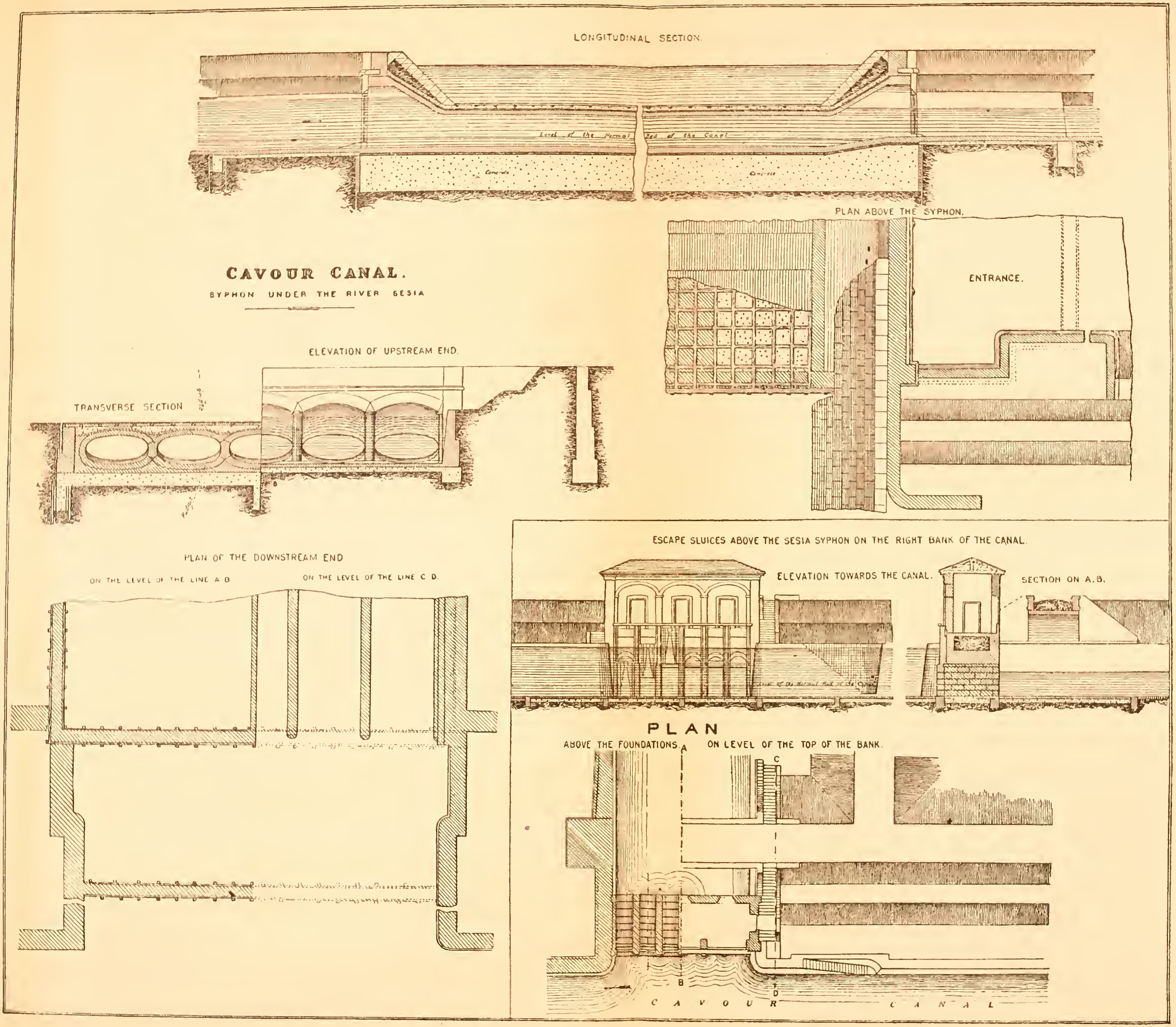
Above the head of the Rotto Canal two other canals, the Depretis and the Ivrea, are built along the hillside east of the valley. Both of these canals have to traverse a broken country in order to reach the higher lands of the plain, but are below much of the best land. Many surveys have been made in an effort to secure a line which would cover the upper part of the plain, but such a canal would have to go through a broken country and coarse, gravelly soil, which together have made the outlay prohibitive. In order to irrigate a part of this land there has been installed at Cigliano, near the head of the Rotto Canal, a pumping station which is operated by water taken from the Depretis Canal and discharged into the Rotto. It has been in operation since 1889 and serves to irrigate about 3,700 acres. Three hundred and eighteen cubic feet of water per second drops from the Depretis Canal 21.3 feet on to four turbine wheels. The water lifted is taken out of the Ivrea Canal through an iron pipe 3.94 feet in diameter, carried down through the pumps, and then lifted from there, the pressure from the Ivrea Canal assisting, of course, in their operation. The drop from the Ivrea Canal to the pumps is 62 feet and the lift from the pumps 131 feet, making the net lift of the water 69 feet. On August 12, 46 cubic feet of water per second was being pumped. This can be increased in times of emergency to 53 cubic feet per second. The pump and pumping house are of excellent design and construction and are kept in perfect condition. The total cost of the plant was $173,700, making the cost of installation $46.95 per acre. In addition to this, the owners of land have to pay the annual cost of raising and applying the water. It is a heavy outlay, but it has proven profitable.

The pumping station was built through an agreement with the Government, both the Depretis and Ivrea canals being State property. Under this agreement the irrigators have free use of the water for power, and until 1898 paid $27.34 per cubic foot per second for the water taken from the Ivrea Canal. In 1898 this charge was raised to $82 per cubic foot per second for the remainder of the concession,

FIG. 1.—DIVERSION GATES FROM CAVOUR CANAL PUMPING STATION NEAR NOVARA.

FIG. 2.—VIEW OF INLET TO SIPHON UNDER SESIA RIVER.

U. S


LONGITUDINAL SECTION.
Level of the Normal Bed of the Canal
Concrete
Concrete
PLAN ABOVE THE SYPHON.
ENTRANCE.
CAVOUR CANAL.
SYPHON UNDER THE RIVER SESIA
ELEVATION OF UPSTREAM END.
TRANSVERSE SECTION
PLAN OF THE DOWNSTREAM END
ON THE LEVEL OF THE LINE A B
ON THE LEVEL OF THE LINE C D.
ESCAPE SLUICES ABOVE THE SESIA SYPHON ON THE RIGHT BANK OF THE CANAL.
ELEVATION TOWARDS THE CANAL.
SECTION ON A.B.
PLAN
ABOVE THE FOUNDATIONS.
ON LEVEL OF THE TOP OF THE BANK.
A
B
C
D
CAVOUR CANAL

which ends December 31, 1905. The four turbines and the pumps which they operate have been in use twenty years and are still in first-class condition. The lands that are irrigated are worth three times as much as the adjacent lands not irrigated, and great regret is felt that the works were not originally built large enough to irrigate the whole of the 20,000 acres of fine land above the Ivrea Canal.

There are two other pumping plants connected with the Government canals in Piedmont. The one at Casale was not visited, but the one now nearing completion, 4.5 miles northeast of the city of Novara, was inspected. This will lift water for the land around the town of Cameri which has hitherto been largely devoted to stock raising. Lack of irrigation has limited the amount of hay which could be raised, and farmers have been compelled to rent meadow land around Novara for winter pasturage. This involved an annual expenditure of $20,000 and serious inconvenience in the moving of stock.

The pumping station which is to supply these farmers with water for irrigation is located at the head of the lateral which runs down to Novara from the Cavour Canal. Here the Cavour runs along the hillside. The water which runs into the lateral has a drop of 10.3 feet, and the pumping station has been arranged so that 882 cubic feet per second of the 988.7 cubic feet per second which is turned into this lateral will pass through two sets of turbine wheels. In one group are two sets of turbines of two each, and in the other one set of three turbines. These will generate about 1,000 horsepower, part of which will be utilized to lift the water through a masonry tube to a measuring basin built on top of the slope above the canal. Here a measuring weir provided with a waste gate will discharge back into the Cavour any surplus water raised.

The land to be irrigated rises to the north with a uniform ascent of about 3.5 feet in 1,000. The tract is about 3.5 miles wide, and the upper side is 70 feet above the water level of the Cavour Canal. Instead of pumping all the water to this height the tract has been divided into four parallel zones. The lift to the upper edge of the first one is 18.8 feet; to the second one, 14.8 feet; to the third, 18 feet. No provision has as yet been made for lifting to the fourth level. All the water—58.76 cubic feet per second—has to be lifted into the basin which supplies the first zone. From this station the water for the next two zones will be elevated by means of electrically driven pumps, the current being generated by electric motors connected with the second group of turbines. The gates which let the water from the canal are sections of a cylinder supported by truss framework and turning on an axis placed above the center of pressure (Pl. XIV, fig. 1). They were made in Novara after designs by Engineers Travaglini and Bertoli. The gates are lifted by means of two chains fastened to the outer circumference and attached to a winch above. Each gate is 21.3 feet

long and 7 feet high. Gates of a similar pattern are now being installed in the head works of the Twin Falls Canal in Idaho.

This pumping station is being built by a private cooperative association of farmers cultivating the land around Cameri. It made an agreement with the Government in September, 1899, by which the Government gives free for thirty years the use of the power necessary to raise 58.76 cubic feet of water per second. The water lifted is sold to the association at $90.72 per cubic foot per second, with a discount of 30 per cent for twenty-nine years. Under this agreement 3,107 acres of land are to be irrigated. Calculations of the quantity of water and the cost of service to farmers are based upon an estimate that it will cost $4,342 to manage, operate, and maintain the plant, and that 1 cubic foot per second will water 62 acres of land. According to this computation, irrigators will have to pay $8,000 a year interest, $4,500 a year for operation, and $5,500 a year for the water purchased, making a total outlay of $18,000 a year, or about $5.80 an acre. In addition to this, provision is made for a sinking fund, amounting to about $10 an acre. This makes the annual charge for water $16 per acre in a region where the annual rainfall is about 30 inches. The fact that this is being done in a country where adjacent lands have been watered for centuries, and where the value of irrigation is not a matter of experiment, but a demonstrated fact, means much for the extension of irrigation in the eastern part of the United States.

THE SIPHON UNDER THE SESIA.

The most important siphon on the Cavour Canal is at the crossing of the Sesia River. Its design is shown in Plate XV and its appearance in Plate XIV, figure 2. It is 820 feet long, composed of 5 oval tubes 16.4 feet in their horizontal and 7.54 feet in their vertical diameter. These tubes are of brick, varying in thickness from 1.77 to 2.3 feet. The concrete foundation on which they rest is 2.6 feet thick. There are masonry walls at the sides of the conduits, above and below, as far as the abutments, which are 4.6 feet thick. Above the mouth of the siphon is a basin 75 feet wide and 213 feet long. Out of it is a wasteway leading into the Sesia.

Protection of this work has been an important source of expense. During violent floods the discharge of the Sesia reaches 28,000 cubic feet per second. This volume of water flowing over the siphon, and at times beating against the protecting walls at the ends, threatens their integrity, and the danger is occasionally increased by the necessity of opening the wasteway and removing the water of the canal.

ADMINISTRATION OF IRRIGATION WORKS BETWEEN THE DORA BALTEA AND TICINO RIVERS.

The Cavour Canal was sold to the Government in 1874, with all the connecting canals, their rights, and privileges. The properties transferred, with the improvements made in them since, represent an outlay of nearly $20,000,000. They are administered by the treasury department, the head office being in Turin, with branch offices in Chivasso, Vercelli, Novara, and Mortara. The general manager, water masters, and ditch tenders are connected with the treasury department; the engineering force with the department of public works. Two branches of the Italian Government have therefore intimate relation with Government irrigation works. The work to be performed by each department is, however, clearly defined.

The general manager superintends the making of contracts or concessions, fixes water rentals, and arranges for the delivery of water to customers. He has charge of all surveys and plans for improvements and for the disposal of water for purposes other than irrigation. He represents the Government in all lawsuits and signs all contracts. The supervisors, ditch tenders, and tax collectors are subordinates of the general manager. The supervisors and ditch tenders manage the canal and regulate the quantities of water turned in and out in order that customers shall be supplied with the amounts contracted for. The tax collectors collect the water rentals, although payments may be made directly to the provincial treasurers. Civil-service regulations govern employment under the treasury department. One-half the vacancies among supervisors must be filled from the ranks of subordinates, and the other half taken from the minor officers in the army. All vacancies among ditch tenders except the lowest rank are filled by promotion. These regulations have given to the canals a body of highly trained and thoroughly competent men.

The chief engineer is connected with the department of public works, but is under the direction of the general manager. He makes plans for improvements or repairs, prepares estimates of expenses for operation and maintenance, and is authorized to do emergency work without instruction from the general manager. He purchases all supplies, superintends the construction of any work undertaken, examines applications for water-right concessions, and is the expert engineering adviser of the general manager on all questions, whether administrative, legal, or technical.

Plans and estimates for any work to cost more than $400 must be approved by the engineers of the department of public works. Contracts which involve an expenditure of more than $8,000 must be let by public bid. Contracts which involve more than $1,600 may be let privately, but must first be submitted to the Ministry of the Treasury. In emergency cases the general manager can make contracts up to $1,600 without this reference.

RATES FOR WATER.

A considerable part of the water carried by State canals belongs to the holders of ancient perpetual rights, which are not affected by tariffs or other regulations. In disposing of the water supply which has no such incumbrance, payments depend upon the use made of the water, the different uses being classified as follows:

Summer irrigation.
Winter irrigation.
Power for operating farm machinery.
Power for industrial establishments.
Water for ice making.

There is a regular tariff for each of these uses except power for industrial establishments, where special agreements are made in each case. The price charged for water for power varies, according to the distance from the head gate, from a maximum of $20 to a minimum of $4 per theoretical horsepower, which is calculated from the difference in level of the water above and below the wheels. In none of the contracts of the Government is there any guaranty against damage because of shortage in the water supply in the streams or from accidents, but where the full amount is not furnished the amount paid is proportionately reduced. As far as possible, contracts for power are made subordinate to contracts for irrigation.

Three methods of regulating charges are used in this system:

(1) Charging according to the area irrigated.

(2) Charging for the quantity flowing through a simple opening in the side of the canal.

(3) Charging for the quantity delivered, measured by regulating either the pressure on an orifice or the depth flowing over a weir.

Prior to 1854 the Government, in farming out its canals, sometimes charged so much for the use of the canal regardless of the amount of water it carried and sometimes for the quantity furnished. Before 1845 the rate where water was charged for by the volume was $35 per cubic foot per second. This was raised in January, 1845, to $65 per cubic foot per second. In 1853 this was succeeded, in the territory west of the Sesia, by a contract with the general association under which $75.45 per cubic foot per second was paid for all water turned into the canals from the Dora Baltea and $93 per cubic foot per second for all water received from the Po. This contract ran for thirty years, ending January 1, 1884. A new thirty-year contract was then made in which the price was fixed at $142 per cubic foot per second. This was reduced in January, 1894, to $126 per cubic foot per second. These prices were based upon measurements made at the head gates without any allowance for losses by seepage or evaporation.

In the district east of the Sesia the Government rents water to different associations at varying rates. Under the Sartirana Canal the

price fixed in 1857 was $185 per cubic foot per second. This was reduced in 1860 to $142 per cubic foot per second; increased in 1870 to $165 per cubic foot per second; and reduced in 1876 to $120 per cubic foot per second.

All the changes made before 1860 were during the time the Cavour Canal was managed by a private association. Since the canal became a State work the tariffs have been twice changed, the present rates being as follows:

(1) The regular price for summer irrigation is $125.75 per cubic foot per second.

(2) The special price for summer irrigation is $82 per cubic foot per second.

(3) A reduction of 20 per cent is made for three years when land is irrigated for the first time.

(4) The price for winter irrigation is $9.84 per cubic foot per second.

(5) The price for power purposes is $1 per horsepower per month.

(6) The price for water furnished by the day during the summer is $2.18 per cubic foot per second.

Where payment for water is based on the area irrigated, the charges are as follows:

(7) Water for rice fields, $7.81 an acre.

(8) Water for meadows, $4.69 an acre.

(9) Water for marcite irrigation, $5.86 an acre.

The average annual income of the system of Government canals in Piedmont for the three years ending 1901 was as follows:

Income from Government canals in Piedmont.

From the sale of perpetual rights	$20, 643. 86
Rent of water for summer irrigation	469, 031. 50
Rent of water for winter irrigation	26, 322. 69
Rent of water for power purposes, industrial plants	33, 687. 57
Agricultural mills, power	2, 493. 17
Rent of public mills	18, 808. 81
Miscellaneous	5, 821. 46
Total	576, 809. 06

The cost of water supplied to irrigators by private canals varies widely. Where these canals are owned by the farmers water is cheap, as the canals cost but little to operate and there is either no charge or only a small State tax for the water diverted from the stream. Where the canals are owned by the nobility or large landowners who rent the surplus left after irrigating their own estates, the rentals are as a rule high. Especially is this true in sections not reached by State canals and where there is no competition. Where State and private canals cover the same areas, competition has lowered both classes of rentals. The distance from the stream also affects rates. This is particularly true along canals close to the Po where the water, if not used, would be wasted. In the portion of Piedmont bordering the Po there are many seepage canals which gather up the waste water from the State canals and the water which percolates from the rice fields above. Rates under these canals are low because they cost little to build, are

not subject to dangers from storms, and the water supply can not always be relied upon. There is often a shortage in the spring when the irrigation on which the seepage flow depends is delayed, and there is often an injurious surplus in the rainy season when the wasteways of the higher canals are open.

In the irrigation of rice water rentals are frequently paid in a share of the crop. It is interesting to note that this plan has also been adopted in the rice districts of Louisiana and Texas. Where the water rental is so paid the share varies from one-fourth to one-seventh, according to the place and the amount of water required. In all such transactions the farmer has to insure against hail.

The greater part of the water from State canals is sold to farmers' associations, the policy being to discourage contracts with individual irrigators. These associations buy at wholesale rates and then retail to their members. They also as a rule lease and operate the secondary canals used in the distribution of the water purchased, where these secondary canals belong to the Government. Many of these associations are important. Among them the one which manages the Montebello Canal controls the watering of 12,600 acres of land in Novara; the Association of Galliata controls the irrigation of 12,000 acres. The largest and most successful is the General Association West of the Sesia.

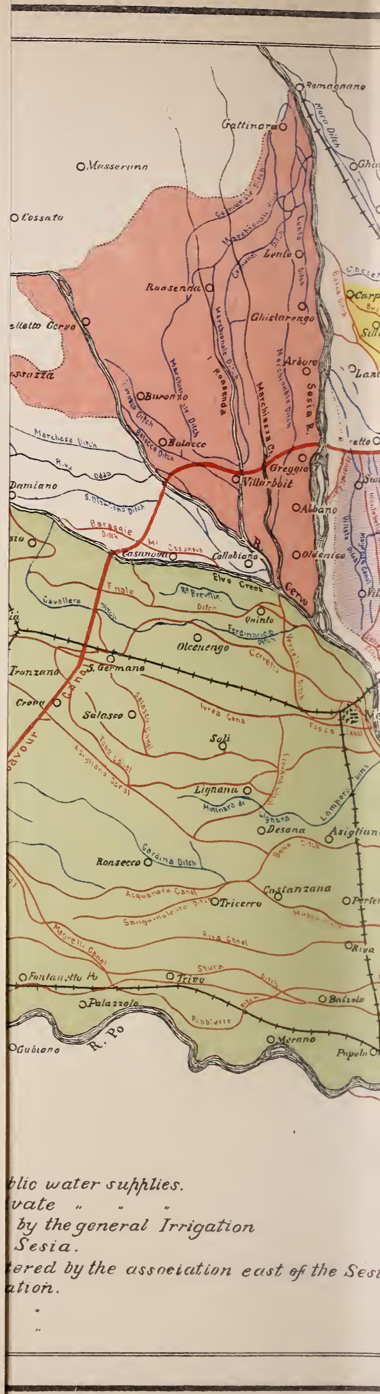
The map (Pl. XVI) will aid in understanding the relation between State and private canals in the irrigation of the country between the Dora Baltea and Ticino rivers. In this map the State canals are colored red and the private ones blue, so it is easy to distinguish them. Altogether about 750,000 acres are irrigated. South of the Cavour nearly all the large canals belong to the State, but between the Sesia and Cervo rivers private works are the rule. These latter are managed by district organizations similar in character to those authorized by the laws of Idaho, Colorado, and California. The green-colored portion of the map shows the boundaries of the General Association West of the Sesia, the yellow, the boundaries of the projected Novara Association, and the uncolored portions show where ditches and canals are operated independently.

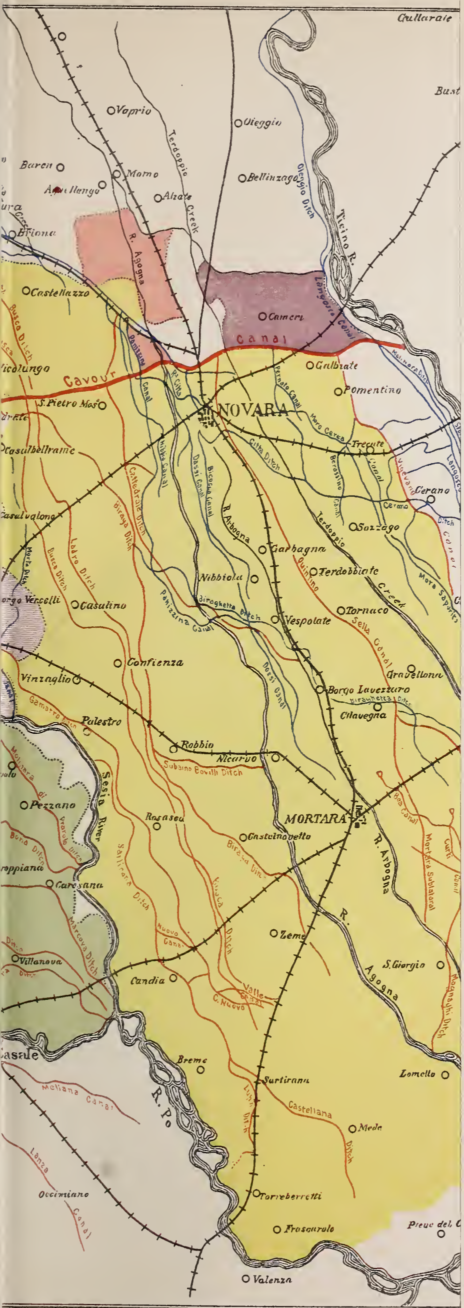
GENERAL ASSOCIATION WEST OF THE SESIA.

The feature of irrigation of most interest in Vercelli is the above-named association. It is more widely known than either the rice fields or costly canals, and has influenced irrigation development in many parts of the world. This unique and effective society is the creation of Count Cavour and is one of his most valuable contributions to the agricultural prosperity of his native province. Its organization grew out of the unsettled water rights, the conflict between public and private ditches, between the appropriators of water from streams and

not subj
always l
the irrig
is often
of the h
In the
of the c
adopted
rental i
accordi
transact
The g
associat
irrigato
to their
canals u
seconda
tions ar
bello C
the Ass
The lar
the Sesi
The r
State a
Dora I
colored
Altoget
nearly a
and Cer
aged by
by the
portion
West o
Associa
are ope

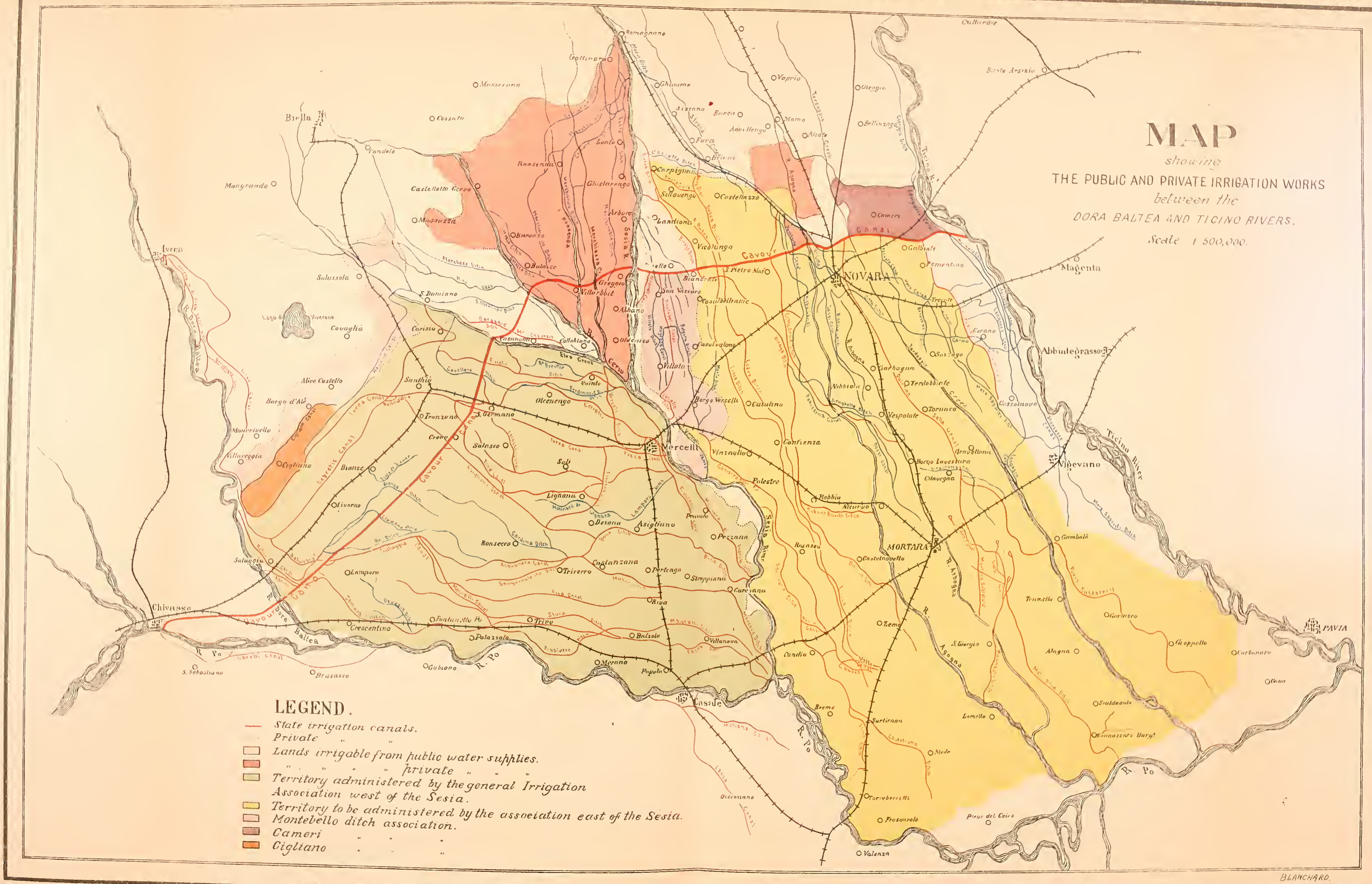
The
named
or cost
parts o
of Cou
agricul
out of
vate di





TO-LITHO WASHINGTON DC

PLATE XVI.



ANDREW B GRAHAM PHOTO LITHO WASHINGTON DC

those who depend on seepage supplies. To put an end to these water-right troubles and to the difference in water rates, Count Cavour took a leading part in a movement to combine all the appropriators and all the canals which distributed water under one management. It is in effect the application of the trust idea in irrigation and is one of its earliest examples. In its general features it is a voluntary cooperation of all the irrigators living in the territory shown on the green-colored portion of Plate XVI. It controls every canal within this territory, fixes the prices of all the water used, manages its delivery, and exercises a large direction in the selection of the crops to be raised.

Some idea of the extent of its operations may be gained from the following statistics. It has 14,000 members, operates 9,600 miles of ditches, has 266 miles of telegraph and telephone lines, supplies water for the irrigation of 141,000 acres of land, and does a business of $600,000 a year. It buys between 1,250 and 1,300 cubic feet of water per second each year from the Government canals. In consideration of this large purchase of water the Government gives the association control of all the secondary State canals through which the water is distributed. In addition to the water bought from the State, the association controls and distributes all the water belonging to private canals and private rights within its territory. Under legislation secured by the society, the owners of these private water rights are compelled to turn the water over to the association because it is illegal for even the Government to sell water to individuals or to any one but the society within its territory. Holders of private water rights are, however, paid for the quantity taken, the price given them being 20 per cent less than that paid to the Government. In addition to the water purchased from the State canals and from private holders, there are ancient perpetual rights to 493.4 cubic feet of water per second, the holders of which are entitled to have this amount of water delivered to them free of cost.

The Association West of the Sesia has assumed for the Government the responsibility of supplying these vested rights, the Government furnishing the water at the head of the distributing canals, with 7 per cent added to compensate for losses by seepage and evaporation. In addition to the water purchased, the association collects a large amount of seepage water, which it supplies to its members. Altogether the association distributes to its members about 2,275 cubic feet of water per second.

The general offices of the association are in Vercelli. Its affairs are directed by a general manager assisted by three undermanagers. The general manager lives in Vercelli, as does one of the undermanagers; the other undermanagers live at Santhia and Trino. The territory

administered by each of the undermanagers is shown on the map (Pl. XVI).

In the irrigation season the regulation of head gates requires the services of 80 water masters, and these in turn are assisted by the twelve or fiteen subordinates in each consorzio or association along the different laterals. The statutes, by-laws, and regulations of the society make a book of 173 pages. Some of the powers exercised seem extraordinary when compared with American practice. For instance, the association determines how many acres in each district may be planted to rice and how many to cultivated crops. The farmers must plant as the association decides, as there is no appeal from the ruling of the superintendent. The reason for conferring this authority on the manager is that it takes seven times as much water to irrigate an acre of rice and three times as much to irrigate an acre of meadow as it does to irrigate an acre of land seeded to corn or wheat. If, therefore, because of high prices farmers wished to extend the area seeded to rice, the association could not supply the water required. Or, if rice growing was suddenly abandoned, there would be a large surplus water supply to be disposed of or the association would be purchasing a large volume of water for which it would have no use, as its contracts for water are not made each year, but for thirty-year periods. Having a definite quantity of water which it must sell, the association requires the farmers to plant crops which will insure a market for it. The man who does not cultivate rice on the land which the association assigns to that crop must pay the same water rent as if he did, and can collect no damage for seepage if he attempts to grow some other crop on lands on which the association has said rice should be grown. Men who waste water or who undertake to make a profit from waste water or seepage water coming from their own land may be fined.

The cost of water to members of the association is determined by adding to the purchase price the expenses of the society for administration, maintenance, and repairs. The books are balanced and computations made in October. The assessments must be paid between November and January—that is, payments are made after the service has been rendered instead of in advance. The promptness with which payments are made is little less than marvelous. In the fifty years that the society has been in operation there has never been an instance of a member failing to pay his assessment within the prescribed time. One reason for this is the severity of the penalty which the society can impose, and that is to refuse to furnish water to such members thereafter.

The members of the association file their applications for water for the next year in the autumn. These applications must state the

amount of water desired and the acreage of the different crops proposed to be grown. The manager of the association, when he examines the applications, may modify them and change the number of acres of corn, rice, or clover for the reasons before explained.

The various officers and employees of the association are under civil-service regulations. Each one when appointed has to serve a probationary period of two years, and after he has served acceptably for this length of time he can not be discharged except for cause. Every question connected with water rates, the relation of individuals to the association or to each other as far as water matters are concerned, may be referred to a court of arbitration composed of three members. This court or board has authority to punish with fines any member of the society found at fault, and the sentences it imposes are considered as law-court sentences and the property of the offender may be seized and sold in order to carry the sentence into effect. Parties to these trials, if they are so disposed, may appeal from these decisions to the law courts, but there is no disposition to do so. In the fifty years during which the society has been in existence, there has never been such an appeal. On the contrary, the celerity with which decisions are rendered, the cheapness of the proceedings, and the popular confidence in the integrity and fairness of the tribunal are so great that there is a constant tendency to bring before it other than irrigation matters for settlement.

In the southern part of the association's territory land rents for $14.35 to $15.60 an acre cash rental. In the northern part it rents for $8.20 to $21 an acre. The annual cost of water to members in the southern part, where the ground is sandy and a large amount of water must be used, is $8.20 to $8.90 an acre. In the northern part it varies from $1.60 to $2 an acre. The low price in the north is, however, more largely due to the fact that cultivated crops take the place of rice and marcite than to difference in the soil.

The society was organized in 1854. Its first contract for water was for a period of thirty years. This was renewed in 1884, so that two-thirds of the second period has now passed. At the outset it was an experiment. The combination of the control of State and private canals under one authority and the exercise of authority over farmers in the crops to be grown were both novel innovations on the previous practice of this district. Their success has been both a public and a private benefit. It has given the farmers a secure water supply and cheaper rates. It has given the State an efficient management of its canals and a stable market for its water supply. Its influence along social and economic lines has been equally valuable. It has been really a little republic of irrigation and has trained farmers to understand and practice self-government and to exercise large adminis-

tration in public affairs. Undoubtedly, the credit for the working out of the original plan is due to Count Cavour, but the success of the administration for fifty years shows great capacity on the part of the officials and a high order of intelligence and civic virtue on the part of the members. To those acquainted with the contentions, jealousies, and anxieties of irrigators under neighboring canals in the Western States, the fact that the measuring boxes on over 9,000 miles of canals have been opened and closed for a half century without a single lawsuit or an appeal to the courts from the rulings of their own officials, is one of the most remarkable features of Italian irrigation. The division of a river among ditches and farms is a complicated problem in transportation and needs the same preliminary organization as a railroad or express line, if each farmer is to get what belongs to him. It also requires that farmers shall submit with the same readiness to the regulations of a canal that they do to those of a railway. It needs a public sentiment which will regard the stealing of water as no different from the stealing of any other commodity, and the opening and closing of head gates without authority as much law breaking as the robbing of a vault or the burglary of a house. Because public sentiment does not so regard interference with head gates or the taking by one irrigator of water which belongs to another, because we have failed to make the welfare of the community superior to the welfare of the individual, there is friction and controversy between farmers and litigation between ditch owners in many sections of the arid region. Competent investigators say that, if this could be done away with, it would add $100,000,000 to the selling value of the lands now irrigated and lessen the annual expenses of operating canals and ditches by more than another million. Legislation alone will not bring this about. It must come through the growth of the spirit of cooperation among the farmers themselves.

SETTLEMENT OF WATER RIGHTS.

For many years water-right controversies were a source of constant annoyance and loss to the irrigators of Piedmont, but during the last half of the century nearly all these have been settled. As the settlement seems to have been final, it was felt highly desirable to know just what procedure had been adopted, and, following the plan pursued in Lombardy, it was decided to choose some typical stream and find out what had taken place there, letting it serve as an illustration for all. The irrigation authorities conferred with urged a visit to the valley of the Dora Riparia River, which waters 20,000 acres of the plain northwest of Turin, outside of the field of Government canals.

The Dora Riparia River carries about 350 cubic feet of water per second when it is low and about 1,100 cubic feet per second when

high. Twenty-one irrigation canals and a large number of power canals utilize its waters. There are numerous ancient diversions below the city of Susa. Until the water reaches Borgone, the stream's great fall supplies power to important industries, which, however, return the water to the river at once. The following table gives all diversions, from above downstream:

Sant' Antonino (Villarfocchiardo)	Right.
Rivoli (San Michele)	Right.
Casellette (Villar Dora)	Left.
Avigliana (Sant'Ambrogio)	Right.
Buttigliera (Sant'Ambrogio)	Right.
Grugliasco (Alpignano)	Right.
Becchia (Alpignano)	Left.
Orbassano (Alpignano)	Left.
Pianezza (Pianezza)	Left.
Venaria Reale (Pianezza)	Left.
Brovere (Rivoli)	Right.
Collegno (Pianezza)	Left.
Barola o Druent (Pianezza)	Left.
Barco (Collegno)	Right.
Putea (Pianezza)	Right.
Conte Collegno (Collegno)	Left.
Cossola (Collegno)	Right.
Lucento Nuova (Collegno)	Left.
Lucento Vecchia (Collegno)	Left.
Martinetto (Turin)	Right.
Parco (Turin)	Left.

The total discharge of all these canals, as nearly as can be determined, is 1,059 cubic feet per second in periods of abundance, 706 cubic feet per second in ordinary periods, 530 cubic feet per second in low-water stages, and 353 cubic feet per second in periods of unusually low water.

The irrigation canals reach only a small part of the broad plain through which the river flows, leaving the greater part crossed in going from Turin to Avigliana hot, dry, and dusty. The large area of land adapted to irrigation and needing water, the high prices for agricultural products, making it possible to pay high prices for water for irrigation, and a surplus during flood season, tempting men to build more canals than the river can fill when low, provide all the conditions needed to create controversies over water rights, and it was desired to ascertain if any such controversies existed. At the upper end of the stream everything was peaceful and satisfactory. There were no evidences of shortage under the ditches in this part of the country and no farmer or ditch manager could recall any grievances of the irrigators farther downstream. This was so contrary to what would have occurred in America and to what was expected from conditions in the lower part of the valley, that a call was made on the Government

civil engineers in Turin to find out what were the facts in the case and their explanation. The statements of irrigators were reported to Mr. Carlo Carosso, engineer in charge of the irrigation office of the department of public works in Turin, and request was made for information regarding the present condition of water rights on the Dora Riparia and as to whether the Government had any part in the protection of these rights. In response to this inquiry the following facts were obtained:

Prior to 1839 the irrigators along this river were in much the same condition as those along many overappropriated streams in the West. More canals had been built than could be filled in midsummer and controversies over water were continuous and bitter. In order to put an end to these a commission was created by royal authority to measure the stream and the grade and size of the different canals diverting water, and to take testimony regarding the priorities of the different diversions and the areas of land served by each canal. The report of this commission was published in 1851. The testimony filled a quarto volume of 400 pages. The gaugings and surveys of the river and canals were reproduced in a second report, which included colored plates, giving the cross sections of the river and of the canals at each head gate and a map of the land served by each canal and ditch at the time the investigation was made. Accompanying these were detailed drawings showing the size and construction of every head gate and the carrying capacity of each canal at the head under certain conditions in the stream. For each canal that is entitled to water these reports are their patents to their supply and obstacles to changes in the claim of any other appropriator. They fix beyond all question the location and size of each head gate at the time these rights were defined.

The report of the commission as to priorities and amounts of water used was based upon an investigation extending over thirteen years, and was accepted by those interested as final. Following the determination of the rights, the Government assumed control over the raising and lowering of head gates in times of scarcity and thus brought peace and security to those who had hitherto had to fight their own battles. It was found that the stream had been overappropriated and that when water was most needed some of the ditches last built were not entitled to anything. These have been practically abandoned. Those having valuable rights came to an understanding with each other and formed a district organization similar to that now being attempted by ditch owners on some of the streams in Colorado, under the irrigation district law of that State. Under this arrangement the supervision of head gates by the Government has been dispensed with, and the association employs a civil engineer to regulate the gates and divide the water among the canals. There are times, however, when his authority is disputed. When this occurs the engineers belonging

to the department of public works are appealed to. The irrigators who believe they are being wronged complain to the prefect of the district. A copy of this complaint is sent to the Government engineers at Turin, one of whom looks over the records of priorities, gauges the amount of water being diverted, and, if need be, takes testimony. If he finds that prior rights are being encroached upon, he regulates the gates, acting very much as water commissioners do under the laws of Colorado, Wyoming, and other States.

The physical conditions on this river are not so favorable as the social conditions above described. Many studies have been made for the purpose of lessening the variation in flow, but so far without result, because of too many diversions and too great a variety in agriculture and industry. There should be substituted a few large canals on the right and left banks, located in such a way as to serve the lands for which water is to be used. The canals now serving these lands could be connected with these new canals as distributors.

AGRICULTURE IN PIEDMONT.

Rice is the most important crop in the provinces of Vercelli and Novara and the chief consumer of the water furnished by the Government canals. The methods of irrigating and cultivating rice in Italy differ somewhat from those in the United States either in the Carolinas or along the Gulf coast. This is due largely to the cheaper labor of Italy.

The land is very carefully leveled, in order that the water may flow in a thin, even film over the entire surface. The fields are divided into sections, with small ridges around each raised high enough to hold the water on the section to a depth of 3 to 5 inches. The method of preparing these sections is similar to the checking of land for irrigation in California, except that it is more carefully graded and the surrounding ridges are not so high. The leveling is all finished in March and seeding begins about April 1. The land where rice is to be sown is covered with a thin film of water. The rice is soaked for a day in order to make it heavier, then sown broadcast, the seeder being followed by a number of barefoot men and women, who tramp the ground up and muddy the water, thus securing a covering of soil for the seed. From the time of seeding until harvest the water is not let off the field, the depth being gradually increased until the latter part of the season, when it is about 4 inches. Eight or ten days before harvest the water is drained off to permit the soil to dry.

In some parts of these provinces rice is grown as a permanent crop, having been grown on some fields continuously for sixty years, but as a rule this is not regarded as good practice, and three years continuous cropping with rice is the usual limit, although in some instances the rotation adopted provides for the continuous growing of rice on some

fields for six years. In the rotation adopted by rice growers it is possible to use wheat, corn, oats, and rye, with lupines for green manure, but in the region visited the principal crop was clover. The rice had been followed by a cultivated crop, and the land then seeded to clover for the remainder of the rotation period. In the districts where rice is not exclusively grown the best results require the cooperation of neighboring farmers in order that other crops may not be damaged by seepage from the rice fields.

Yields are largely influenced by the number of years rice is grown upon a particular field. The first year after the rotation period is always the best. One farmer, who cultivates 1,100 acres of land, gave the following as the average yield of his fields for the years rice was grown in the rotation:

Yields of rice.

	Pounds per acre.
First year	4,215
Second year	3,510
Third year	3,040
Fourth year	2,330

The growing of rice requires a large volume of water. In 1902 the farmer above referred to rented 7 cubic feet of water per second for a rice field of 132 acres. This gave a duty of 1 cubic foot per second for 19 acres. He paid for this $87.46 per cubic foot per second, which is less than the wholesale price the association pays the Government under the agreement of 1894. This is due to the income derived from the sale of water gathered up from drainage and seepage ditches and allowance made for distributing water to holders of ancient rights. From these sources so much water is obtained that costs nothing that it more than pays the running expenses of the association and makes the retail price less than the wholesale.

Rice land is valuable, prices in these provinces varying from $370 to $410 an acre. Rough and uncleaned rice sold last year for 2 cents per pound; cleaned rice for 3.5 cents per pound.

The most serious evil with which the rice grower has to contend is a kind of grass which grows so rapidly that it can not be drowned out and which, if not removed, tends in time to ruin the crop. The method of getting rid of it is to pull it up. This is done by hand, the laborers working in the water.

Hail is another menace to the rice crop. As a precaution against injury from it, the Government loaned cannon to certain districts. These are stored in small houses in the midst of the fields where they can be discharged when a storm occurs. The belief in the effectiveness of these explosions has, however, about disappeared.

A disease known as "brusone," which attacks the rice about the time of ripening, destroying in a short time the whole crop, is a third

FIG. 1.—VIEW OF FARMYARD, SHOWING REAR OF HOUSE AND A PART OF CONNECTING BARNS.

FIG. 2.—VIEW OF FARMYARD, SHOWING IMPLEMENTS.

The pile of brush at the right is for fuel and was cut from ditch banks.

evil with which the Italian rice grower has to contend. It affects most fields where rice has followed meadows, and Bertone, a rough variety of rice, is most susceptible. The disease is liable to develop in times of sudden change from hot to cold nights and the twilight mists seem to be the principal means of its diffusion.

Meadows stand next to rice with respect to acreage. Clover and alfalfa meadows predominate because they form a part of the rice rotation, but there are some marcite fields in districts where rice is not allowed or can not be grown. Marcite can be grown only where it can be watered in winter; that is, where a water supply can be had from springs or seepage.

Orchards and gardens have little importance and are grown only in the vicinities of towns. Wheat, rye, and oats have an acreage in about the order given. They form a part of the rotation in the rice fields, wheat being grown in the compact soils and rye in the less compact and drier lands, while oats are frequently grown as the crop preceding rice after the meadows have been plowed up. Wheat is planted in the fall, the land being sown to clover in the spring. This grows in the stubble, producing a crop of hay after the wheat has been harvested. Oats are sown in the spring, with clover or grasses. In July the oats are harvested and later on the crop of clover is harvested. Hemp and flax are grown on small farms, but have no commercial importance.

Rice growing and silk raising do not flourish together. Keeping the ground covered with water kills the mulberry trees, nor can they be made to thrive in adjoining fields because of the seepage which almost always exists.

Plate XVII shows two views of a farmyard on a rice plantation, where over 100 men and women were employed as field laborers. Rice thrashers and hullers were operated by water power taken from irrigation ditches, and the equipment of machinery was in many respects equal to that of a modern American farm, although the low price of farm labor causes many things to be still done by hand which in America would be done with tools. Many of the tools, such as hoes, scythes, and rakes are cruder and heavier than those in use in the United States, the difference in pattern of scythes and hoes being shown in the implements in Plate XVII, figure 2.

DUTY AND COST OF WATER.

Rice is grown on more than half the irrigated area of Novara and Vercelli, hence more than half of it has to be kept continuously under water throughout the growing season. This thin film of water becomes hot, making the losses from seepage and evaporation enormous. Taking the whole district north of Mortara, including rice fields, cultivated

crops, and marcite, the average duty of water is about 1 cubic foot of water per second to 28 acres. South of Mortara the duty falls in places to the surprisingly low figure of 1 cubic foot per second to 5 acres, if no account is taken of the waste water which escapes at the lower end of fields. The failure to measure waste water makes statistics as to water duties in this part of Italy misleading. Nevertheless, it is probable that in the southern part of Piedmont the net average duty is not more than 1 cubic foot per second to 30 acres.

Because of the large amount of water required frequent complaints were heard as to its cost. The prices charged by the General Association West of the Sesia are not excessive where a duty of 1 cubic foot per second to 50 acres is reached, but where, as in some cases, 1 cubic foot per second irrigates only 15 acres the cost of water, under the tariff, is $10 per acre. This is regarded as the limit of cost in rice irrigation, and where 1 cubic foot per second irrigates only 5 acres the tariff charge for water makes the cost prohibitive. On the farms where rice is excluded and cultivated crops are largely grown the duty is quite high, and the cost of water under the present tariff is usually only $1.50 to $1.80 per acre.

In applying water it is kept running over the rice fields constantly. Cultivated crops are irrigated twice and meadow lands every week or ten days. The estimated average duty of water for the whole of Piedmont, taken from the report quoted from above, is as follows:

Estimated average duty of water in Piedmont.

Rice	1 cubic foot per second for 26.5 acres.
Meadow	1 cubic foot per second for 62 acres.
Field crops	1 cubic foot per second for 93 acres.

STRUCTURES FOR MEASUREMENT AND DISTRIBUTION OF WATER.

The problems of water measurement on the Cavour and its connecting canals are difficult of solution. Orifices are not suited to the measurement of large volumes of water such, for example, as have to be measured from the main to secondary canals. It is difficult with weirs to get rid of the velocity of approach. Especially is this true at head gates of secondary canals. Varying conditions of pressure and velocity have made it necessary for the Government engineers to make reductions and corrections for the theoretical formulas. The results are, from the nature of things, uncertain and unsatisfactory. To correct this the Government has made an appropriation of $60,000 for the construction of a hydraulic testing station to be used in determining the corrections necessary in the formulas used in measuring water on canals. The results of these experiments will have great value in advancing engineering knowledge throughout the world.

The civil code of Italy makes the module the legal standard of measurement in agreements for water. It is equivalent to 100 liters per second (3.53 cubic feet per second). Either the weir or the orifice may be used in its measurement. Many of the ancient measures are still in use. All of these were based upon a gate or opening of a given form. Altogether a large number of orifices of different shapes and sizes are in use.

The following description of some of these measures is taken from the report of the Italian department of agriculture before referred to.

PRACTICE FOLLOWED IN OLD PIEDMONT FOR THE DISTRIBUTION OF WATER.

In ancient Piedmont three measures were used—the wheel, the oncia, and the module.

(1) *Piedmont wheel.*—The water wheel, invented and proposed by Francesco Demenico Michelotti, was "that quantity of water that freely and by pressure passed through a vertical gate of a 'liprando' foot square, made of a very thin flat stone and placed with the upper side at the level of the water." This wheel was divided into twelve parts equal to oncias.

In the table of equivalents, compiled under a ministerial order by a special commission in 1845, the discharge of the Michelotti wheel is estimated to be 335.138 liters per second; therefore each oncia was estimated to be 27.928 liters per second.

(2) *Piedmont oncia.*—Until 1730 a measure known as "oncia" was used in the diversion of water from the State canal of Caluso. This measure was an imitation of that which from 1585 was in use in the Milan territory, with the substitution of the linear measure of Piedmont for that of Milan, so that the dimensions of the gate and the head above the opening which in the Milan oncia are expressed in oncias of the Milanese bracchio are in the Caluso oncia expressed by an equal number of oncias of the liprando foot.

The gate is 4 oncias high, 3 wide, with a head above the opening of 2 oncias of the liprando foot, and its discharge according to the table of equivalents was fixed at 24.053 liters.

(3) *Oncia of Ignazio Michelotti.*—Ignazio Michelotti succeeded his father in the direction of the State canals and introduced for the measure of water the use of the wheel, and, as the gates at the level of the water could not be easily used, he substituted another standard of measure known as the oncia, that was estimated to be equal to one-twelfth of the wheel invented by his father. The new oncia was the quantity of water flowing from a gate 4 oncias wide, 3 high, and with a head above the opening of 4 oncias of the liprando foot. But calculations made showed that the oncia of Ignazio Michelotti gave a discharge greater than one-twelfth of the wheel proposed by his father. The discharge of the Ignazio Michelotti oncia was fixed in the table of equivalents at 28.86 liters.

(4) *Albertini module.*—This was a module used in ancient Piedmont. It is described in article 643 of the Albertino civil code as follows:

In new concessions of water in which shall be agreed or expressed a constant quantity of flowing water, called also a concession at a taxed gate, the quantity conceded shall be in all public acts expressed in "modules of water."

A module is that quantity of water that by its own pressure alone and with a free fall passes through a rectangular opening placed so that two of its sides are vertical,

2 decimeters wide, 2 decimeters high, and opened in a thin slab along which the water is flowing and is maintained with its highest surface 4 decimeters higher than the lowest side of the gate.

In the above-mentioned table of equivalents the discharge of the Albertino module is fixed at 57.938 liters.

PRACTICE FOLLOWED FOR THE DISTRIBUTION OF WATER IN THE ANCIENT PROVINCE OF LOMBARDY.

(a) *Milan official oncia.*—This is a type upon which were based many of the standards of measure used in Piedmont and Lombardy. "It corresponds to a volume of water that by pressure alone flows through a rectangular gate with a width of 3 oncias (0.14873 meter) of the Milan bracchio, 4 oncias high (0.19831 meter), with a head above the opening of 2 oncias (0.09916 meter), opened in a slab 3 oncias thick." It is the only gate that is provided with a true regulator, which, while not perfect, is nevertheless very ingenious.

The structure of the irrigation gate was conceived and proposed by the Engineer Soldati in 1571. The rule of Poncelet and Lesbros does not apply here to the form of the regulating structure itself, as on changing the width of the gate contraction is not equally modified and the discharge is as much greater as the gate is larger. Turazza says:

It is in this sense that the assertion of Brunacci is true, "that the Milanese practice is not free from error, where, in order to obtain a double, treble, etc., discharge, the width of the measuring gate is doubled or trebled." A large gate, for instance, three times as wide as the module or oncia, gives a discharge a little greater than 3 oncias.

Colombo, in his valuable work, gives for the discharge of tne Milanese official oncia the following figures:

Milanese oncia from a gate of 1 oncia, 35 liters.

Milanese oncia from a gate of 10 oncias, 47 liters.

This gives an idea of the increase in discharge with the increase in the number of oncias supplied by the gate. In the table of equivalents the Milanese oncia is estimated to have a discharge of 34.5 liters.

(b) *Novara oncia.*—Imitating the Milanese oncia, the Novara oncia is the quantity of water flowing from a gate placed under conditions identical with those of the Milan oncia and with similar dimensions—with this difference only, that these dimensions are based on the oncia of the Novara bracchio instead of the Milan bracchio. The Novara bracchio is 0.606213 meter, divided into 12 linear oncias. The resulting Novara module (oncia) is 4 oncias high, equivalent to 0.202 meter; 3 oncias wide, equal to 0.1515 meter, with a head above the opening of 2 oncias, equal to 0.1010 meter; and with a thickness of the stone in which the opening is made of 3 oncias, equivalent to 0.1515 meter. The discharge of this gate is estimated to be 36.117 liters in the table of equivalents.

(c) *Pavia oncia.*—This was modeled after the Milan official oncia, except that the linear oncias are based upon the Pavia bracchio of 16 oncias.

		Meter.
Width	3 oncias =	0.1179
Height	4 oncias =	.1572
Head	2 oncias =	.0786

Its discharge in the manual of Calandra is fixed at 19.5 liters.

(d) *Novara Rodigio.*—It has not been possible to obtain information upon the form of this gate and the conditions under which it must operate. It seems, however, that the rodigio indicated the quantity of water necessary to operate an ordinary mill wheel, and that its discharge was about 6 Novara oncias. Sospizio, in

his valuable work upon Irrigation in Piedmont, gives the discharge of the Novara rodigio as 207 liters.

REMARKS AND TABLE OF EQUIVALENTS.

Professor Turazza prefaced his estimates of the discharge of various modules by some remarks that it is necessary to report here:

The modules that we have described above present such various conditions as to make very difficult the correct estimates of their discharges, at least without having recourse to direct and repeated experiments. In these the flow is almost always impeded. Very seldom is the water so quiet at the gate as to be considered stagnant, and this gate is almost never made of thin stone. On the contrary, in the Cremona module and in those patterned after the same model, the true measurer of the water is not a gate but a conduit of appreciable length. In investigating their discharge I was obliged to abandon the use of the calculations, at least every time when, by direct experiments, more exact information could be obtained than was possible by the rules for openings. It is only to those modules for which the opinion of the practical man is still desired that I tried to apply these rules, and here I am obliged to say that the discharge must be considered as only approximate, and even then within wide limits, perhaps.

These observations of the illustrious master should be kept in mind by those who desire to use the data regarding discharges referred to in the following table:

Table of equivalents, Italian units for water measurements.

Units in use in various provinces in Italy.	Cubic feet per second.	Italian module.	Albertini module.	Wheel of F. D. Michelotti.	Oncia of Ignazio Michelotti.	Oncia of Caluso.	Oncia of Milan.
Italian module	3.5315	1.0000	1.7241	0.2986	3.4650	4.1841	2.8985
Albertini module	2.0482	.5800	1.0000	.1732	2.0097	2.4267	1.6811
Wheel of F. D. Michelotti	11.8233	3.3480	5.7724	1.0000	11.6008	14.0083	9.7043
Oncia of Ignazio Michelotti	1.0192	.2886	.4975	.0862	1.0000	1.2073	.8365
Oncia of Caluso	.8440	.2390	.4120	.0713	.8281	1.0000	.6927
Oncia of Milan	1.2183	.3450	.5948	.1030	1.1954	1.4435	1.0000
Oncia of Novara	1.2752	.3611	.6225	.1078	1.2512	1.5107	1.0466
Oncia of Pavia	.6886	.1950	.3362	.0582	.6756	.8159	.5652
Oncia of Lodi	.6198	.1755	.3025	.0524	.6081	.7340	.5086
Oncia of Crema	.6374	.1805	.3112	.0539	.6254	.7552	.5231
Oncia of Cremona	.7183	.2034	.3506	.0607	.7047	.8510	.5895
Quadretto of Verona	5.1332	1.4536	2.5062	.4341	5.0367	6.0820	4.2133
Quadretto of Mantua	11.1005	3.1433	5.4194	.9388	10.8914	13.1518	9.1110
Mole of water or rodigio	7.3100	2.0700	3.5689	.6182	7.1724	8.6610	6.0000

Units in use in various provinces in Italy.	Oncia of Novara.	Oncia of Pavia.	Oncia of Lodi.	Oncia of Crema.	Oncia of Cremona.	Quadretto of Verona.	Quadretto of Mantua.	Mole of water or rodigio.
Italian module	2.7693	5.1282	5.6980	5.4001	4.9164	0.6872	0.3181	0.4831
Albertini module	1.6062	2.9743	3.3048	3.2127	2.8515	.3990	.1845	.2802
Wheel of F. D. Michelotti	9.2716	17.1692	19.0769	18.5484	16.4601	2.3032	1.0651	1.6314
Oncia of Ignazio Michelotti	.7992	1.4800	1.0644	1.5988	1.4188	.1985	.0918	.1394
Oncia of Caluso	.6618	1.2256	1.3618	1.3240	1.1745	.1644	.0760	.1198
Oncia of Milan	.9554	1.7691	1.9658	1.9113	1.6961	.2373	.1097	.1666
Oncia of Novara	1.0000	1.8517	2.0575	2.0005	1.7753	.2484	.1148	.1744
Oncia of Pavia	.5400	1.0000	1.1111	1.0803	.9587	.1341	.0620	.0942
Oncia of Lodi	.4860	.9000	1.0000	.9722	.8628	.1207	.0558	.0848
Oncia of Crema	.4998	.9256	1.0284	1.0000	.8874	.1241	.0574	.0872
Oncia of Cremona	.5632	1.0430	1.1589	1.1268	1.0000	.1399	.0647	.0983
Quadretto of Verona	4.0254	7.4543	8.2826	8.0538	7.1465	1.0000	.4624	.7022
Quadretto of Mantua	8.7047	16.1194	17.9105	17.4144	15.4537	2.1624	1.0000	1.5185
Mole of water or rodigio	5.7324	10.6153	11.7948	11.4681	10.1769	1.4240	.6585	1.0000

A visit was made to the school of engineers in Turin, where Professor Taricco, assistant lecturer in geology, showed their extensive equipment for experiment and instruction in hydraulics. It includes a series of open canals in the university grounds, equipped with head

gates and measuring boxes of different forms for the measurement of water in open channels, and a large and varied assortment of apparatus for measuring the flow of water through orifices, over weirs, and under different pressures. The collection of current meters, all of which were of different patterns from any seen in the United States, was of especial interest. A modification of the Woltman wheel, which is simple in design and is the best liked by the engineers talked with in Italy, seems worthy of trial in this country. Pitot's tube is more extensively used in Italy than with us. Registers for recording stream heights used in America are superior to those seen in Italy, but their weirs and orifices are built more accurately and solidly than ours, and, therefore, give better results.

O

LIST OF PUBLICATIONS OF THE OFFICE OF EXPERIMENT STATIONS ON IRRIGATION AND DRAINAGE—Continued.

Bul. 105. Irrigation in the United States. Testimony of Elwood Mead, irrigation expert in charge, before the United States Industrial Commission June 11 and 12, 1901. Pp. 47. Price, 15 cents.

Bul. 108. Irrigation Practice among Fruit Growers on the Pacific Coast. By E. J. Wickson. Pp. 54. Price, 15 cents.

Bul. 113. Irrigation of Rice in the United States. By Frank Bond and George H. Keeney. Pp. 77. Price, 30 cents.

Bul. 118. Irrigation from Big Thompson River. By John E. Field. Pp. 75. Price, 10 cents.

*Bul. 119. Report of Irrigation Investigations for 1901, under the direction of Elwood Mead, chief. Pp. 401. Price, 50 cents.

Bul. 124. Report of Irrigation Investigations in Utah, under the direction of Elwood Mead, chief, assisted by R. P. Teele, A. P. Stover, A. F. Doremus, J. D. Stannard, Frank Adams, and G. L. Swendsen. Pp. 336. Price, $1.10.

Bul. 130. Egyptian Irrigation. By Clarence T. Johnston. Pp. 100. Price, 30 cents.

Bul. 131. Plans of structures in use on irrigation canals in the United States, from drawings exhibited by the Office of Experiment Stations at Paris, in 1900, and at Buffalo, in 1901, prepared under the direction of Elwood Mead, chief. Pp. 51. Price, 60 cents.

*Bul. 133. Report of Irrigation Investigations for 1902, under the direction of Elwood Mead, chief. Pp. 266. Price, 25 cents.

Bul. 134. Storage of Water on Cache la Poudre and Big Thompson Rivers. By C. E. Tait. Pp. 100. Price, 10 cents.

Bul. 140. Acquirement of Water Rights in the Arkansas Valley in Colorado. By J. S. Greene. Pp. 83. Price, 5 cents.

FARMERS' BULLETINS.

Bul. 46. Irrigation in Humid Climates. By F. H. King. Pp. 27.

Bul. 116. Irrigation in Fruit Growing. By E. J. Wickson. Pp. 48.

Bul. 138. Irrigation in Field and Garden. By E. J. Wickson. Pp. 40.

Bul. 158. How to Build Small Irrigation Ditches. By C. T. Johnston and J. D. Stannard. Pp. 28.

Bul. 187. Drainage of Farm Lands. By C. G. Elliott. Pp. 40.